Use of Scrap Tires as a Substitute of Fine Aggregates in Asphalt Pavement

By

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the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

(Miss Koh Moi Ing)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2005

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NOORHANAN BINTI TALIB

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ABSTRACT

The management of scrap tires has become a growing problem in recent years. Scrap tires represent one of the several special wastes that are difficult to handle. Thus, there is a need to solve the rubber disposal problem. Recently, scrap rubber has been used in asphalt highway construction, but there are still some limitations in the rubber application. Scrap tires are believed to be able to produce better performance asphalt pavement, which can provide quieter riding environment, and less defective pavement. The purpose of the research is to determine the performance of the asphalt pavement with the existence of scrap tires, compare with the conventional asphalt pavement. The research will be conducted by adding the scrap tires to substitute small part of fine aggregate in the asphalt mixtures. The scrap tires will be cut into small pieces and mix together with the conventional mixtures of coarse and fine aggregates as well as filler. The rubber modified asphalt are designed using Marshall Mix Design and tested using Wheel Tracking Test and Beam Fatigue test to evaluate pavement performance on fatigue and permanent deformation. The main purpose to conduct the research is to enhance the conventional pavement performance. It is successfully determine the performance of Rubber Modified Asphalt mixture is better than the conventional mixture. Perhaps the research can help to promote the used of scrap tires in asphalt pavement for better performance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

ORGANIZATION OF THE THESIS

The report will include the purpose of the research on the Rubber Modified Asphalt (RMA) Pavement and the current findings of the research through series of laboratory experiments done. Beside that, the report will also compare the performance of conventional mixtures with the Rubber Modified Asphalt (RMA).

Chapter 1 consists of the overview of the research, which describe the introduction, problem statement and objectives. It indicates the beginning of the research and problems driving to the existence of Rubber Modified Asphalt (RMA) Pavement, and the purpose of the research.

Chapter 2 explaining the properties of the Rubber Modified Asphalt Pavement, properties of rubber (scrap tires), and advantages and disadvantages of the Rubber Modified Asphalt compare to the Conventional Asphalt Pavement as what have been found out from earlier researches.

Chapter 3 illustrates the methodology of the research, as well as the method use to conduct the research and procedures of laboratory testing required in this research.

The results and discussion of the laboratory experiment conducted during the research are included in **Chapter 4**. The chapter also elaborates the analysis of the results.

Chapter 5 concludes the finding of the research for the whole year and also the recommendations of the author.

1.1 Introduction

The research is conducted due to the arising problems of flexible pavement in Malaysia. Most of the problems are regarding the deformation of pavement, shorter pavement's life, cracking, fatigue, and high maintenance cost. Therefore, the research is performed to find out the alternative in improving the performance of the conventional asphalt pavement by using the scrap tires.

Scrap tires can be incorporated into asphalt paving mixes using Dry Process of mixtures, which the crumb rubber is used as a portion of fine aggregate. The process is introduced in the United States to modify the properties of the conventional asphalt mixtures. The process can be used for hot mix asphalt paving in dense graded, open graded, or gap graded mixtures. In the Dry Process, the crumb rubber is used as a substitute for a small portion of fine aggregate, which is usually 1 to 3 percent by weight of the total aggregate in the mix. The rubber particles are blended with the aggregate prior to the addition of the asphalt cement. The resultant product is sometimes referred as Rubber Modified asphalt Concrete (RUMAC). The size of rubber particles is graded and the gradation commonly used in rubberized asphalt pavement is between 2.0 mm to 5.0 mm.

For the present research, the process used is similar to the Dry Process. The rubber particles will substitute a small portion of fine aggregates, which will be ranging from 1 to 3 percent of total weight of fine aggregate. Eventually, the rubber will be mix with coarse aggregates, fine aggregates, filler and binder to form asphalt mix. The differences between process adopted in current research and Dry Process are; the rubber particles do not have to be separated from the fiber inside the tires, the size of rubber particles used is in single uniform size which is 2.0 mm, dense graded is used, the used binder content is lower than mixtures of Dry Process which is 4.5 to 6.5 percent of binder content, and motorcycle's tires are used to produce rubber particles need in experiments..

The improvements of RMA in construction industries in U.S have proved to be significant and beneficial to the industries. But it was not yet widely used in Malaysia due to high production cost. Reason for further researching on Rubber Modified Asphalt in this Final Year Project is to simplify the production process and reduce production cost, which will introduce a new "simple process" which is similar to "dry process". The production cost of RMA can be simplified by cutting scrap tires into a single size rubber cubes instead of rubber particles in various sizes. This is believed to be able to reduce the cost of production and save great efforts in producing rubber particles with various sizes. Beside, this research is expected to further improve other performance of flexible pavements.

1.2 Problem Statement

In Malaysia, two types of pavements were commonly used in road construction, namely, flexible pavement and concrete pavement. However, majority of the roads are constructed using the flexible pavements. Generally, most of the flexible pavements deteriorate faster than rigid pavement, which in turn required more maintenance to the flexible pavement roads. The deterioration of flexible pavement arises from deformation under traffic loading, generally associated, in the later stages, with cracking. This stimulated more research in improving the quality and durability of the pavement.

The used of scrap tires as a substitute of the fine aggregate in the RMA mixtures should result in higher resistant to permanent deformation compared with that of conventional mixtures. However, Jon A. Epps (1994) found that fatigue life is generally improved when crumb rubber is added by Dry Process. Addition of crumb rubber also believed to be able to enhance pavement performance in terms of reflective cracking. Thus, it is expected that dry process will improve the performance of the pavement in terms of deformation and cracking.

Besides that, Tom Kuennen (2004) reported that the problem regarding the noisy environment resulting from the impact of the tire with the pavement is believed to be alleviated by substituting the crumb rubber into the conventional mixture.

1.3 Objective and Scope of Study

The research studied the effectiveness of the scrap tires in improving the performance of the Conventional Asphalt Pavement in various aspects such as deformation, fatigue life and noise reduction.

The main objectives of the research are;

1. To produce successfully the Rubber Modified Asphalt (RMA) that uses of scrap tires cubes as a substitute of fine aggregates in Asphalt Pavement.
2. To identify possible properties improvements by Rubber Modified Asphalt.
3. To evaluate the effects and extent of the improvement in pavement properties in Rubber Modified Asphalt.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

All pavements ultimately fail but application of the appropriate treatment at the correct time or introduction of additives materials can significantly prolong their life. One definition of engineering failure is that a characteristic falls below some threshold of acceptability.

An example would be a wearing course, which is regarded as having failed when its skid resistance falls below the critical value for that part of the network. It may well be the case that other characteristics such as structural strength or the degree of cracking or rutting have not reached critical levels. The wearing course will last at most 20 years before rutting excessively but will probably need a surface treatment such as surface dressing to restore skid resistance, and seal cracks during those 20 years.

2.2 Fatigue and Rutting Characteristics

Fatigue of bituminous mixtures under repeated flexure is an important factor of pavement design. It is the most common pavement failure for flexible pavement or asphalt pavement. There are many types of cracking, such as alligator cracking, and block cracking.

Alligator or fatigue cracking does not normally occur until after numerous loadings and then increases rapidly as the pavement weakens. In climates with either large variations in temperature or very cold temperatures, asphalt pavements develop transverse and longitudinal cracks from temperature stresses. These cracks usually break down and spall under traffic. It is a series of interconnecting cracks caused by the fatigue failure of an asphalt surface or a stabilized base under repeated traffic loading. The cracking initiates at the bottom of the asphalt surface or stabilized base, where the tensile stress or strain is highest under a wheel load. The cracks propagate to the surface initially as one or more longitudinal parallel cracks. After repeated traffic loading, the cracks connect and form many-sided, sharp-angled pieces that develop a pattern resembling chicken wire or skin of an alligator as shown in figure below.

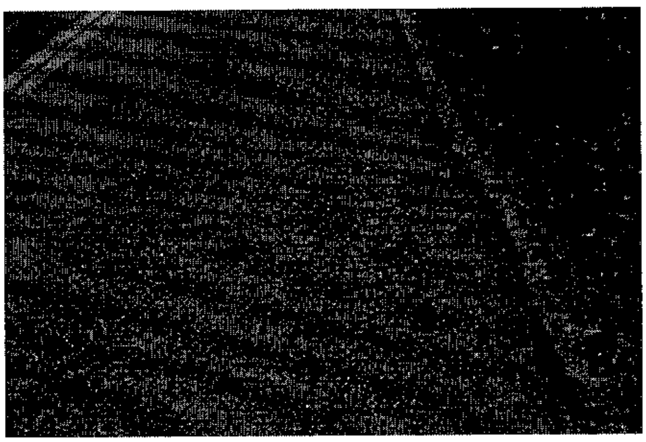


Figure 2- 1: The Fatigue Cracking Occur on the Pavement

The pieces are usually less than 1 ft on the longest side. Alligator cracking occurs only in areas that are subjected to repeat traffic loadings. It would not occur over an entire area unless the entire area was subjected to traffic loading. Alligator cracking does not occur in asphalt overlays over concrete slabs. Pattern-type cracking, which occurs over an entire area that is not subjected to loading, is classified as block cracking, which is a load-associated distress. The cracking is measured in square feet or square meters of surface area.

Block cracks divide the asphalt surface into approximately rectangular pieces. The blocks range in size from 1 to 100 ft2. Cracking into larger blocks is generally categorized as longitudinal or transverse cracking. Block cracking is caused mainly by the shrinkage of hot mix asphalt and daily temperature cycling, which result in cyclic stress and strain. It is not load associated, although loads can increase the severity of the cracks. The occurrence of block cracking usually indicates that the asphalt has hardened significantly. Block cracking normally occurs over a large portion of pavement area, but sometimes will occur only in non-traffic areas. The cracking is measured in square feet or square meters of surface area.

Rutting in another way is a surface depression in the wheel paths; see **Figure 2-2**. Pavement uplift might occur along the sides of the rut. However, in many instances, ruts are noticeable only after a rainfall, when the wheel paths are filled with water. Rutting stems from a permanent deformation in any of the pavement layers or in the subgrade, one usually caused by a consolidation or lateral movement of the materials due to traffic loads. Rutting can be caused by plastic movement of the asphalt mix either in hot weather or from inadequate compaction during construction. Significant rutting can lead to major structural failures and a potential for hydroplaning. Rutting is measured in square feet or square meters of surface area, for a given severity level based on rut depth.

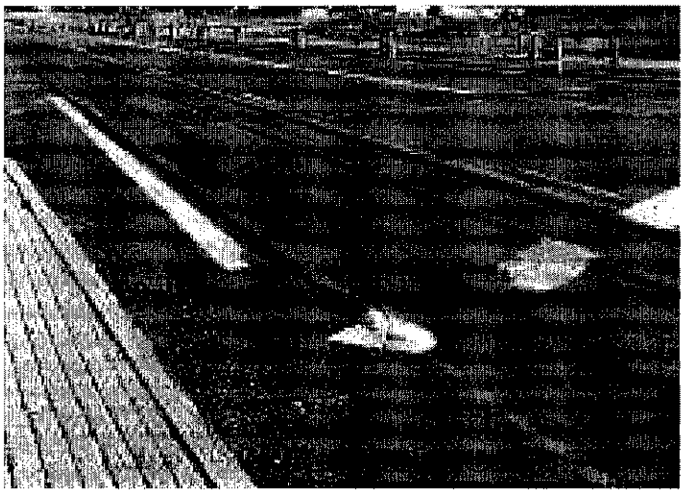


Figure 2- 2: The Rutting Occur on the Pavement

2.3 Application of Scrap Rubber in Asphalt Pavement

Several researches have been done by mixing additives to improve the performance of asphalt mixture in flexible pavement construction. One of the methods that believed to be able to produce better performance of the asphalt mixtures is by using scrap tires as substitute of fine aggregates. There are two generally accepted processes for incorporating scrap tires in asphalt mixtures; (1) Rubber Modified Asphalt Mixtures, and (2) Rubber Asphalt Mixture. Both processes are recognized as dry process and wet process, respectively.

This chapter will introduce the processes used to produce Rubber Modified Asphalt (RMA) mixtures; namely Dry Process and Wet Process. Both processes will be discussed in detail in the next section in this chapter.

The Dry Process, which is most frequently used method in the United States was originally developed in the late 1960's in Sweden and is marketed in this country under the trade name PlusRide by EnviroTire. The PlusRide technology is a patented process. In this process, 1 to 3 percent granulated crumb rubbers by weight of the total mix is added to the paving mix. The granulated rubber consists of rubber particles ranging in size from 4.2 mm (1/4 in.) to 2.0 mm (No. 10 sieve). The target air voids content of the RMA mix is 2 to 4 percent, which is usually attained at asphalt binder content of 7.5 to 9 percent as clarify by Michael Heitzman (1991). A generic Dry Process technology was developed in the late 1980's to early 1990's to produce dense graded hot mixtures. This concept uses both coarse and fine crumb rubbers to match aggregate grading and to achieve improved binder modification. The crumb rubber may need pre-reaction or pretreatment with a catalyst to achieve optimum particle swelling. In this system, rubber content does not exceed 2 percent by weight of total mixture for surface courses.

There are several advantage and disadvantages of using both Dry Process and Wet Process. As for Dry Process, it is a simple process as it substitute small portion of fine aggregate, rather than Wet Process as the scrap rubber needs to be dispersed in liquid asphalt at high temperature for several hour for the rubber to be melt before mixing with the asphalt. Dry Process requires lower cost of cutting the rubber and consisted of many rubber sizes compare to Wet Process. Wet Process needed higher cost in preparing the equipment for melting and standard small size of rubber particles to facilitate digestion. Furthermore, the Wet Process of rubber modified asphalt require higher binder content than conventional mixes as the rubber asphalt is significantly more viscous than conventional asphalt binder and the un-reacted rubber particles will act as a solid filler, thus increasing the binder volume. Also, resultant product from the Wet Process of rubber asphalt is determined to have a long-term deformation resistance as compare to the Dry Process.

2.4 Application of Scrap Rubber in Asphalt Pavement in Malaysia

In Malaysia, the application of scrap tires (rubber) in asphalt pavement is not widely used, but there is research about the rubberized pavement. One of the road constructed using the rubberized pavement is the R1 road (protocol road) in Putrajaya. The product is called **Bituminas PREMIUM-R** which is produced by incorporating crumb rubber mixture into plain bitumen in specific proportions. It is 100 percent locally-made product and has been proven to be the choice in road construction. The characterization of crumb rubber mixture is carried out to ensure consistency in the quality of Bituminas PREMIUM-R produced. The addition of rubber into bitumen enhances the strength and visco-elasticity characteristic of bitumen which is reflected in the improved performance and durability of pavement. Some of improvement in properties of pavement constructed using Bituminas PREMIUM-R include higher resistance to rutting and cracking, higher modulus and higher skid resistance. Bituminas PREMIUM-R is suitable for use in both dense and porous mix and road trials at Putrajaya and Nilai respectively have proven the superiority of Bituminas PREMIUM-R.

2.5 Types of Asphalt Mixtures with Rubber Substitution

As mentioned in previous section, there are two types' resultant products with Rubber Substitution. They are (1) Rubber Modified Asphalt Mixtures (Dry Process), and (2) Rubber Asphalt Mixture (Wet Process).

2.5.1 Rubber Modified Asphalt Mixtures (Dry Process)

Rubber Modified Mixtures is in which 1 to 3 percent is added to the mix by weight of aggregate (substitute for a small portion of the fine aggregate) before asphalt is introduced. Mix design for Rubber Modified Asphalt Mixture is normally made using the Marshall Method. Rubber Modified Asphalt Mixtures relatively having lower Marshall Stability values as well as higher Marshall Flow values as compared to conventional mixes. Consequently, stability and flow values only guidance as to the relative position of the mix on the design curve but can not be used for selecting or specifying asphalt content for mix design. Previous studies indicate that resistance to permanent deformation of such mixes is reduced compared with that of conventional paving mixes. However, fatigue life is generally improved when crumb rubber is added during the Dry Process [2].

Generally, all rubber mixtures have flatter slopes than the control mix, which indicate that rubber mixtures are more elastic than the control mixtures and at short load durations Rubber Modified Asphalt Mixtures should outperform conventional mixes.

2.5.2 Rubber Asphalt Mixture (Wet Process)

Rubber Asphalt Mixture is a mixture in which 18 to 26 percent tire rubber is dispersed in liquid asphalt at high temperatures for several hours is used as binder in asphalt mixtures. Due to the required reaction of the asphalt and rubber process, the rubber particle size must be considerably small to facilitate digestion.

Like Rubber Modified Asphalt Mixtures, Rubber Asphalt Mixtures require higher binder contents than conventional mixes. There are several reasons for this increase, which are: (1) The rubber asphalt significantly more viscous than the conventional asphalt binder, thus requiring thicker film coatings, and (2) The un-reacted rubber particles act as solid filler, increasing the binder volume but not necessarily adhesive characteristic.

The longer pavement life claimed for Rubber Asphalt Mixture is attributed to higher viscosity and impermeability of Rubber Asphalt Mixture. These properties have decreased thermal cracking, potholing, deformation, and reflective cracking in most states in which tests were performed. Studies by the Alaska Department of Transportation showed decreased stopping distances as a result of Rubber Asphalt Mixture being more flexible and preventing ice formation [5].

There is certain disadvantages of using the wet process, which are; (1) High cost of preparing the equipment to melt the rubber with the asphalt, (2) Require small standard size of rubber particles to facilitate digestion, and (3) Require high binder content as the rubber asphalt is significantly more viscous than conventional asphalt binder and the un-reacted rubber particles will act as a solid filler, thus increasing the binder volume.

2.6 Properties of Scrap Tires

The use of the scrap tires as a substitute of aggregate in Asphalt Pavement is due to the properties of the rubber itself. The very characteristics that make them desirable are long life and durability, and tires are thermal set polymers means that they cannot be melted and separated into their chemical components.

Other properties that make the scrap tire or rubber particles more desirable as an alternative in improving the performance of the Conventional Asphalt Pavement are;

1. Rubber is water resistant, so that it will not cause water ponding,
2. Rubber can stand extreme temperature (hot weather),
3. Rubber resistant to scuff, scratch and indentation,
4. Perform skid and stain resistant,
5. Rubber also immune to biological degradation,
6. Easy to be cut, shaped and customized as needed, and
7. Rubber (scrap tires) is a renewable source.

2.7 Comparison between Binder Properties and Rubber Properties

Bitumen used for road construction are viscous-liquid; semi solid materials, consisting essentially of hydrocarbons and their additives, which are soluble in trichloroethylene. Below are the other properties of bitumen.

1. Penetrating-grade bitumen,
2. Black or brown in color,
3. Waterproofing and adhesive properties,
4. Soften gradually when heated,
5. Less susceptible to temperature change,
6. At low temperature behaves almost elastic (brittle) solid,
7. At high temperature and long loading times, behave as viscous fluid, and
8. At intermediate temperature, behave as viscous-elastic range.

From both properties of rubber and bitumen, there is significant difference, which are;

1. Rubber is more viscous than bitumen when it is melted,
2. Rubber has high elasticity than bitumen,
3. Rubber can with stand high temperature, and
4. At low temperature, rubber will not brittle.

2.8 Advantages and Disadvantages of Rubberized Asphalt Pavement

Due to what have been explained before, the crumb rubber modifier was reported to have some advantages and disadvantages compare to the Conventional Asphalt Pavement. Table 2.1 and Table 2.2 summarize and specifying the advantages and disadvantages of the Rubberized Asphalt Pavement [6].

Items	Advantages
Cost	• Reduced life cycle, maintenance, contracting, inspection, sound barrier cost.
Construction	• Reduces construction noise and public and traffic inconveniences.
Mixture	• Increases the temperature viscosity and provides more ductility to the mix at low temperatures.
Road Performance	• Provides cracking resistance and long-lasting color marking, increases surface toughness and flexibility characteristics.
Vehicles	• Provides greater skid resistance, better road holding, and less spalling of the surface, reducing vehicles damage.
Scrap Tires	• Preserves landfill space and provides a tire disposal solution.
Noise	• Reduces traffic noise.
Drainage	• Improves drainage and reduced motorway spray.

Table 2- 1: Advantages of Rubberized Asphalt Pavement

Items	Disadvantages
Construction	• For wet process, rubberized asphalt pavement must to be used within hours of production, then the mobile units required.
Cost	• Increased initial cost per mile. These costs include increase asphalt content, energy consumption, and rubberized material. • Increased the investment costs due to modification requirements that have to be made to the plant, paving, design, and mixing equipment. • For wet process, increased the cost of mobile equipment and setup.
Environment	• Concerns about air emission, worker safety, and recycle ability.
Mixture	• Increases mixing temperature. • Requires unique aggregate gradation, asphalt, and filler content design, and a greater overall filler and asphalt cement volume. • For wet process, deteriorate at elevated temperatures.

Table 2- 2: Disadvantages of Rubberized Asphalt Pavement

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section briefly describes the flow of the research to be done. The main point of the research to be smoothly and successfully conducted is the preparation of the specimens, which are the rubber particles. The flow can be summarizing as show by Figure 3.1 below. The figure shows the Flow Chart of the steps or procedure for the research.

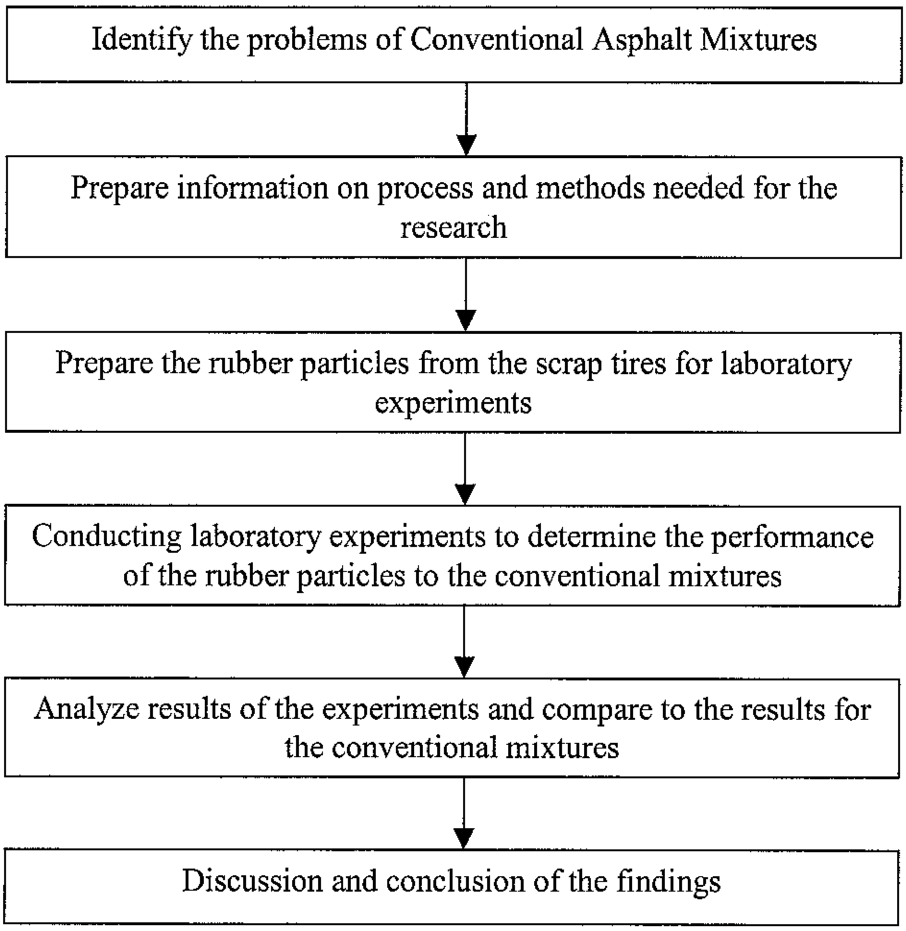


Figure 3- 1: Flow Chart of Research

3.1.1 Identify the Problems of Conventional Asphalt Mixtures

For the research to achieve its objectives, firstly, the problems of the existing Conventional Asphalt Pavement have to be identified to find out the improvement needed. The Conventional Asphalt Pavement subjected to shorter pavement life due to deformation, thermal cracking, and reflective cracking. Also there is a need in improving the skid resistant, as well as noise reduction abilities.

Thus, the research aims to improve the weaknesses of the Conventional Asphalt Pavement by adding the crumb rubber that replace a small portion of the fine aggregates, which result in production of Rubber Modified Asphalt mixture. The research is to determine the effectiveness of the Rubber Modified Asphalt mixture in improving the weaknesses of the Conventional Asphalt Pavement.

3.1.2 Preparing Information on Process and Methods for Research

In order to start the project, information is needed such as process and materials to be used for the research, laboratory experiment, and many more. It is to assure that the research is following the right method in order to have successful result.

Scrap tires from motorcycle has been identified as materials for the research, as well as coarse aggregate, fine aggregate, cement as filler, and bitumen as binder. The motorcycle tires is choose due to easy to cut into pieces as it is not very thick compare to tires from motorcars. The research will be using the Dry Process for preparation of Rubber Modified Asphalt mixture. Various laboratory experiments have been identified to be conducted for RMA mixture during the research.

3.1.3 Prepare Rubber Particles from Scrap Tires for Laboratory Experiment

The additive material used for the research is the scrap tires from motorcycle which will be cut into small pieces to replace small part of fine aggregates. The size of rubber particles cubes to be used is 2.0 mm x 2.0 mm x 2.0 mm, and the percentage to be added is varies from 1 to 3 percent of total weight of fine aggregate. The specimens will not be melted but to be added in the mixtures during mixing.

Reason to used scrap motorcycle tires as the tire is easy to cut into small pieces for laboratory experiment. The size of the rubber particles shall be 2.0 mm as refer to the previous research which the rubber particles size is ranging from 4.2 mm to 2.0 mm [4].

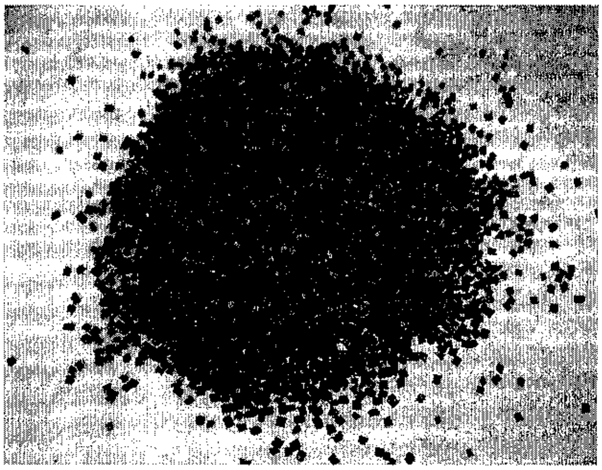


Figure 3- 2: Rubber Particles (2mmx2mmx2mm)

3.1.4 Conducting Laboratory Experiments

Several laboratories analysis and testing are identified to be conducted during the research period. They are;

1. *Sieve Analysis*, to find the proportions of the mixtures,
2. *Marshall Stability Test*, to determine optimum binder content and stability of the specimens,
3. *Wheel Tracking Test*, to determine the rutting performance of the mixtures,
4. *Beam Fatigue Test*, to determine the fatigue life and level of cracking of the mixtures, and
5. *Noise Testing*, to determine the level of noise reduction compare to the conventional asphalt mixtures.

Half of the laboratory experiment is estimated to be completed in the first half of the year and the other half of the experiments during the second half of the year. As for noise measurement test, suitable methods are still on research as there is no specific test and equipment to conduct the test.

3.1.5 Analysis Results of the Experiments

Once the result of the laboratory experiments is obtained, analysis will be conducted to find out the differences in the performance between Rubber Modified Asphalt mixtures and Conventional Asphalt mixtures. Beside that, the laboratory experiment for conventional mixtures will also be conducted and analyze as a control mixtures for comparison.

It has been identified from the previous study that the air voids content would be different compare to conventional mixtures, and the binder content also expected to be higher than those of conventional asphalt mixtures. The differences will be verified from Marshall Stability Test. Other results from the laboratory experiments also will be analyzed to evaluate the RMA performance.

3.1.6 Discussion and Conclusion of the Findings

Finally, the discussion and conclusion of the results that has been analyzed will be made to determine whether the objectives of the research have been fulfilled or not. The conclusion will include the comparison between the Rubber Modified Asphalt mixtures and the Conventional Asphalt mixtures, in various aspects, such as deformation, cost, fatigue life, and stability.

3.2 Testing and Analysis

For the research, several laboratory testing and analysis will be conducted as to identify the performance of the Rubber Modified Asphalt mixtures, compare to Conventional Asphalt mixtures.

The tests identified for the research are;

1. Sieve Analysis,
2. Marshall Stability Test,
3. Wheel Tracking Test,
4. Beam Fatigue Test, and
5. Noise Measurement.

3.2.1 Sieve Analysis

The test is conducted to determine the proportions of the mixtures (coarse and fine aggregates, and filler) for preparation of Marshall Mix samples for Marshall Stability Test. Below are the procedures of the testing.

<u>Procedures:</u>

Coarse Aggregate and Fine Aggregate

1. 3 kg of coarse aggregate and 0.75 kg of fine aggregate (sand) is weighted to the nearest gram.
2. The BS Sieve used for sieving of coarse aggregate and fine aggregate is weighted. For coarse aggregate, the BS Sieve size uses are 28 mm, 20 mm, 14 mm, 10 mm, and 5 mm. For fine aggregate, BS Sieve size 5 mm, 3.35 mm, 1.18 mm, 425 μm, 150 μm and 75 μm.
3. Then, the stack of sieves is placed in the mechanical sieve shaker in decreasing size of BS Sieve. The sample is poured inside the sieves and closed with the lid. The sieve is then shaken for 20 minutes for both coarse and fine aggregates.
4. After that, the stack of sieves is removed from the shaker and the material remaining on each sieve together with the sieve is weighted.
5. The materials remaining on each sieve is determined by finding the difference between the weight obtained in Step 4 and Step 2. From the weight retained in each sieve, percentage of materials passing each sieve is determined.
6. Finally, semi logarithmic (S-curve) plot of percentage passing versus grain size (sieve size) is plotted.

Filler

1. 100 g of filler sample (cement) is weighted to the nearest gram.
2. Each BS Sieve used is weighted. The BS Sieve sizes used are 425 μm, 150 μm and 75 μm.
3. The sample is poured inside the sieves and the stack of sieves is placed in the mechanical sieve shaker to be shaken for 15 minutes.
4. After that, the stack of sieves is removed and each sieve with the remaining of the sample is weighted.
5. The weight retained in each sieve is determined by finding the weight differences obtained in Step 4 and Step 2. Then, the percentage of materials passing each sieve is calculated.
6. Finally, S-curve of percentage passing versus grain size (sieve size) is plotted.

Design Proportions

1. After the sieve analysis is conducted, the percentage of coarse aggregate, fine aggregate, and filler is estimated based on the range of percentage specified; Coarse Aggregates (48% - 65% specified), Fine Aggregates (35% - 50% specified), and Filler (5% - 8% specified) [7]. The estimated values should be within the range given for the materials.
2. Then, the estimated percentage of each materials is multiplied with the percentage retained of each materials determined earlier from the sieve analysis test.
3. After that, the total aggregate is determined by adding the percentage determined in Step 2, for each sieve size ranging from 28 mm (coarse) until 75 μm (fine and filler).
4. From the total aggregate determined, the total percentage passing used is calculated, and S-curve of total percentage passing versus the sieve size is plotted.
5. In the same graph the JKR Standard for allowed design curve is also plotted. It is to determine whether the proportions estimated for each material is within the JKR Standard or not. If not Step 1 until Step 5 is repeated.
6. Once the design curve is obtained within the JKR Standard the proportion estimated will be use for the Marshall Stability Test.

3.2.2 Marshall Stability Test

Marshall Stability Test is conducted once the design proportions for the mixtures are determined from the Sieve Analysis. The procedures of the test are the same for Conventional Asphalt mixtures, except for additional of crumb rubber which will replace a small amount of fine aggregates.

For the research, the crumb rubber used is from 1 to 3 percent of weight of fine aggregates, while the binder content will be range from 4.5 to 6.5 percent. The binder used is bitumen.

Procedures:

Preparation of Asphalt Specimens

1. Based on the proportions determined earlier, sample of coarse and fine aggregates and filler is prepared, and heat in the oven at 150^0 for 24 hours. The binder (bitumen) and the 100 mm mould are also kept in an oven at 150^0. The total of mixture should be 1200 g after added with crumb rubber.
2. Then, the materials is placed in the mixer and mixed dry for 1 minute. After that, appropriate amount of crumb rubber (1% - 3%) and bitumen is added (4.5% - 6.5%) to the aggregate. The mixing is continued until all particles are coated with bitumen and the crumb rubber is melted.
3. After that, the mixtures is poured into the steel mould, and compacted with steel rod to assure the mixtures are evenly distributed in the mould.
4. The mould is then placed inside the Gyratory Machine to be compacted and gyratory for 150 revolutions.
5. Then, the mould is removed from the machine and placed at the extrude machine to be extruded from the mould. The height of the specimen is recorded.
6. Three specimens are prepared for each percentage of binder content.

Testing Asphalt Specimens

1. The specimens are placed inside the water bath and heat to a temperature of 60°C for 30 minutes.
2. The specimen is then placed in the Marshall Testing rig. The breaking head of Marshall Testing rig is also conditioned to 60°C.
3. Then the specimen is load radially at a constant rate of strain of 50.8 mm/min.
4. The stability of each specimen as the maximum load that the specimen could withstand is determined.
5. The stability value obtained is corrected using the appropriate coefficient factor **(Refer Appendix 1)** [8].
6. From the data, the relationships of density versus binder content, stability versus binder content, porosity versus binder content, and flow versus binder content, is plotted.

3.2.3 Wheel Tracking Test

The purpose of Wheel Tracking Test is to determine the rutting performance of the Rubber Modified Asphalt mixtures and Conventional Asphalt mixtures. Both then will be compared to find the improvement of the rutting performance. The test can also determine the deformation level of both mixtures.

Procedures:

Test Specimen Preparation and Testing of Specimen

1. The materials mixing procedure is similar to the Marshall Stability Test but the total mass here is 10 kg instead of 1.2 kg for Marshall Stability Test. The optimum binder content determined earlier in Marshall Stability Test will be used for preparation of conventional asphalt mixtures and Rubber Modified Asphalt (RMA) mixtures slab sample.
2. Either square brown paper or grease can be applied onto the internal base of the square mould for the ease of dismantling of the mould later.
3. The mixed materials is evenly spread into the mould and tamped to ensure an even distribution before compacting with the hand compactor.
4. The mixed materials (10 kg) needed to be compacted layer by layer, which overall should be three layers.
5. The mixed materials needed to be spread until it is about 5 mm above the top of the mould if 30 kg roller with 310 mm face width is used for compaction. Compaction will be carried out until the flat face level with the top of the mould.
6. Sample is left to cool in room temperature before removed from the mould.
7. The sample needed to be cured in an oven of 45°C before ready to be tested in the Wheel Tracker Machine which is also have been set to the same temperature.
8. The test will be run for 2000 cycles with two passes, forth and back in 45 minutes and the total rut depth is observed from the computer connected to the Wheel Tracking Machine.

3.2.4 Beam Fatigue Test

The aim of the test is to determine the fatigue life and level of cracking of the Rubber Modified Asphalt mixtures and Conventional Asphalt mixtures. The level of cracking for the Rubber Modified Asphalt mixture should be less than the Conventional Asphalt mixtures as what stated in the previous study.

Procedures:

Specimen Preparation and Testing

1. The required beam sample size to be prepared is 63.5 mm x 50 mm x 400 mm with density of 2.23. The mass of mix materials to be prepared is 2.4 kg.
2. The mix materials were then compacted in the mould by using the special mould's lid designed for compaction purposes.
3. Beams were then cured in the room temperature before tested with the beam fatigue test equipment.
4. The test will be conducted in control sinusoidal strain mode of loading.
5. The sample is heated to 25°C before tested.
6. The test will be tested in the middle strain level which is about 100 to 200 micro strain. Beam fatigue also can be tested using high strain level (600 to 800 micro strains) and low strain level (200 to 300 micro strains).

3.2.5 Noise Measurement

Noise Measurement test is the test for noise level produce by the vehicle's tires when passing by the pavement. It is believed that the Rubber Modified Asphalt (RMA) Pavement should be able to produce quieter pavement compare to the Conventional Asphalt Pavement.

For noise measurement test, specific method to used is still to be identify as the suggested methods are not fully accurate and suitable for laboratory testing, which are; (1) By measuring the noise level during the Wheel Tracking Test, but it is afraid it will not be accurate as disturbance from the sound of the machine itself, and (2) By laying the Rubber Modified Asphalt (RMA) mixture in certain area and measure the noise level as car passing on the road. It is assume to be the better way to measure the noise, but it require hard work as the pavement have to be lay and compacted at site, which also require large amount of the RMA mixtures, and it will cost a lot.

The research will not performing the Noise Measurement Test as the method to measure the noise is still not yet identified and also time consuming. So, perhaps that it will be conducted later by other researcher.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The Rubber Modified Asphalt mixture was successfully produced using the new "Simple Process", which is the substitution of small portion of fine aggregates. Several laboratory experiments have been conducted to identify and verify the performance of the Rubber Modified Asphalt mixture.

The laboratory experiments, which are Sieve Analysis Test, Marshall Stability Test, Wheel Tracking Test, and Beam Fatigue Test, are completely conducted. It is grateful that the experiments completed before the end of the semester and the results required have been obtained. The results that have been obtained from all the laboratory experiments are show and discuss in this chapter.

All the results have been obtained successfully from the laboratory experiments conducted throughout the research period.

4.2 Sieve Analysis

Figure 4-4 shows the final result of the Sieve Analysis which is the proportions determined for the mixtures. From the results of the sieving analysis, the mix proportions are conformed to the range specified by the JKR, which shown in **Table 4-4**. The design proportions calculated, the proportions for **coarse aggregate, fine aggregate and filler** are, **49 percent, 43 percent and 8 percent** of total mixtures weight of 1200 g respectively. The proportions of the mixtures are use for Conventional Asphalt Mixtures.

For the Rubber Modified Asphalt Mixtures, one to three percent of rubber particles will replace a portion of fine aggregate. Example, for one percent rubber specimens, the mixture will consist of 49 percent coarse aggregate, 42 percent fine aggregate, one percent rubber particles, and 8 percent filler.

Coarse Aggregate

BS SIEVE SIZE (mm)	SIEVE WEIGHT (kg)	SIEVE WEIGHT + SAMPLE (kg)	WEIGHT RETAINED (kg)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
28	1.653	1.653	0	0	0	100
20	1.407	1.497	0.09	3	3	97
14	1.118	2.543	1.425	47.5	50.5	49.5
10	1.106	2.243	1.137	37.9	88.4	11.6
5	1.326	1.669	0.343	11.43	99.8	0.2
pan	0.793	0.797	0.004	0.13	100.0	0.0

Table 4- 1: Sieving Result for Coarse Aggregate

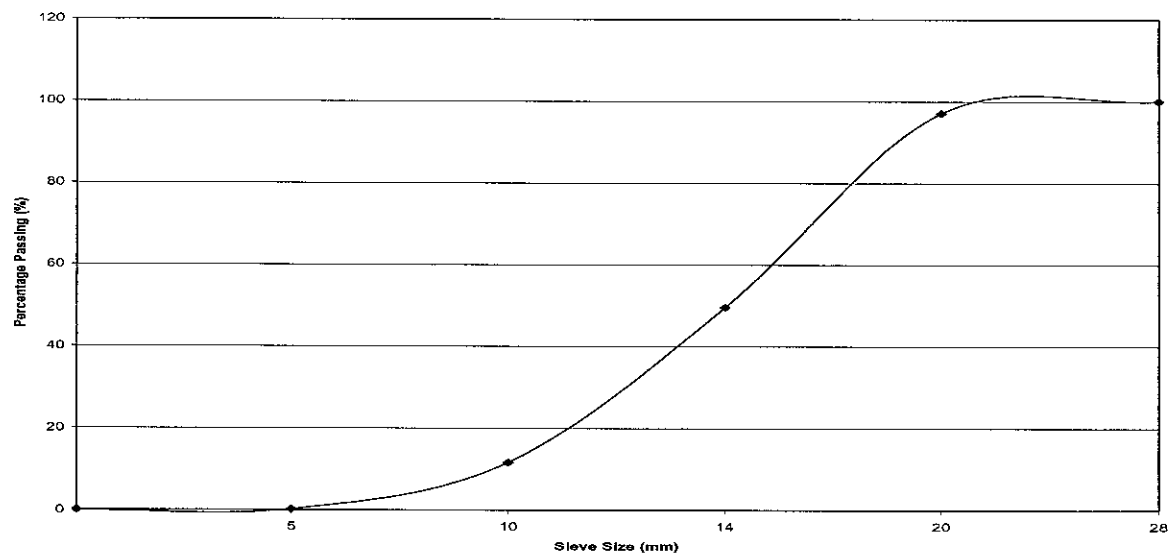


Figure 4- 1: S-curve for Coarse Aggregate

Fine Aggregate

BS SIEVE SIZE (mm)	SIEVE WEIGHT (kg)	SIEVE WEIGHT + SAMPLE (kg)	WEIGHT RETAINED (kg)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
5	1.326	1.338	0.012	1.6	1.6	98.4
3.35	1.167	1.187	0.02	2.67	4.3	95.7
1.18	0.999	1.2	0.201	26.8	31.1	68.9
0.425	0.857	1.195	0.338	45.07	76.1	23.9
0.15	0.87	1.041	0.171	22.8	98.9	1.1
0.075	0.84	0.841	0.001	0.13	99.1	0.9
pan	0.793	0.799	0.006	0.8	100.0	0.0

Table 4- 2: Sieving Result for Fine Aggregate

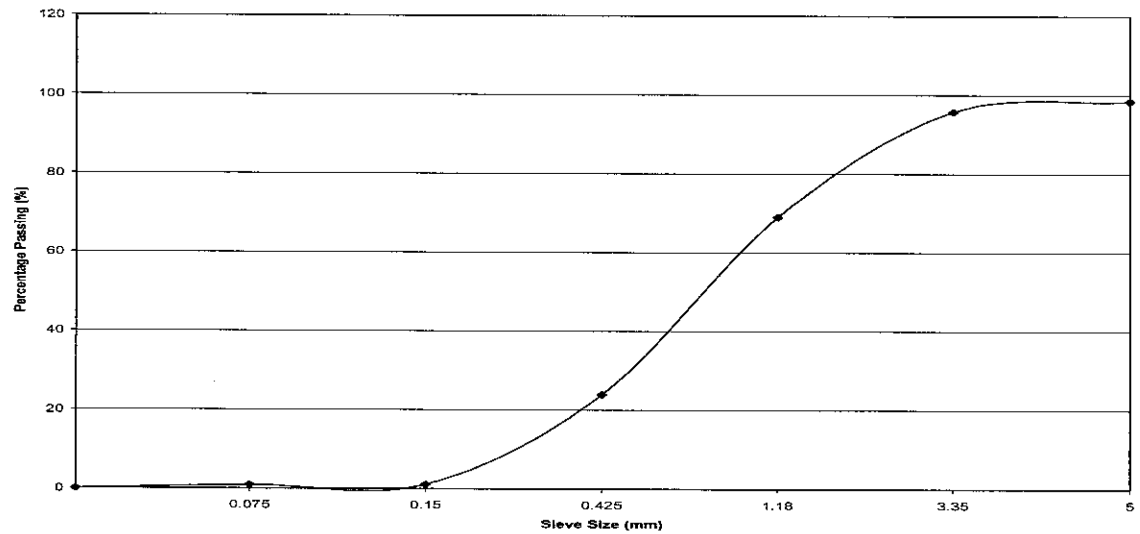


Figure 4- 2: S-curve for Fine Aggregate

Filler

BS SIEVE SIZE (mm)	SIEVE WEIGHT (kg)	SIEVE WEIGHT + SAMPLE (kg)	WEIGHT RETAINED (kg)	PERCENTAGE RETAINED (%)	CUMULATIVE PERCENTAGE RETAINED (%)	PERCENTAGE PASSING (%)
0.425	0.86	0.86	0	0.00	0.00	100.00
0.15	0.872	0.878	0.006	6.00	6.0	94.00
0.075	0.836	0.881	0.045	45.00	51.0	49.00
pan	0.773	0.821	0.048	48.00	100	0.00

Table 4- 3: Sieving Result for Filler

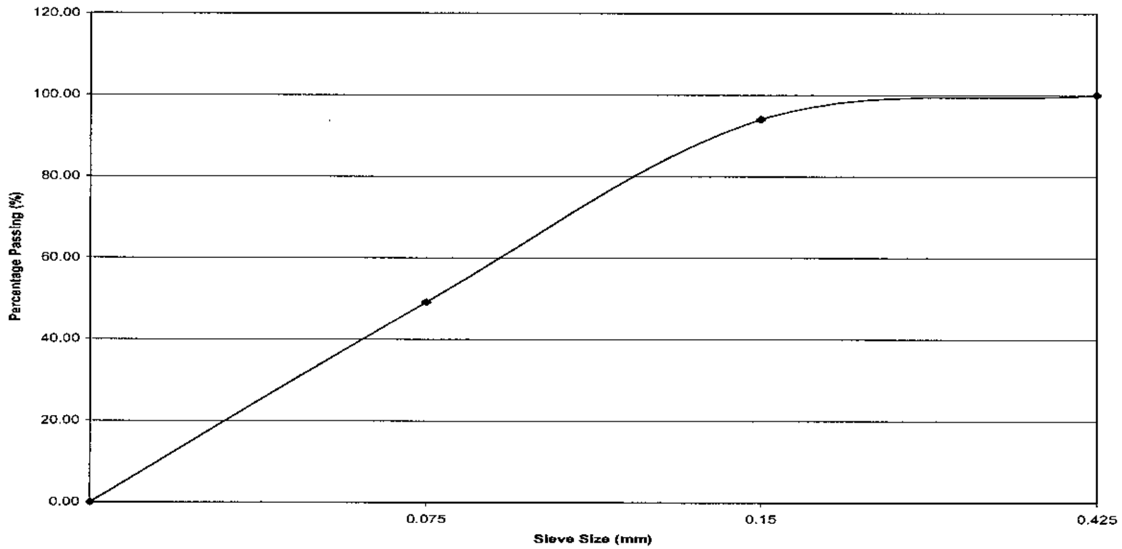


Figure 4- 3: S-curve for Filler

B.S Sieve	Wearing Course
	% Passing By Weight
28.0 mm	100
20.0 mm	76 – 100
14.0 mm	64 – 89
10.0 mm	56 – 81
5.0 mm	46 – 71
3.35 mm	32 – 58
1.18 mm	20 – 42
425 µm	12 – 28
150 µm	6 – 16
75 µm	4 - 8

Table 4- 4: JKR Design Envelope

RETAINED ON SIEVE SIZE	COARSE	49%	FINE	43%	FILLER	8%	TOTAL	CUM %	TOTAL AGGREGATE
28	0	0					0	0	100
20	3	1.47					1.47	1.47	98.5
14	47.5	23.275					23.275	24.745	75.3
10	37.9	18.571					18.571	43.316	56.7
5	11.43	5.6007	1.6	0.688			6.29	49.60	50.4
3.35			2.67	1.1481			1.15	50.75	49.2
1.18			26.8	11.524			11.524	62.28	37.7
0.425			45.07	19.3801	0	0	19.38	81.66	18.3
0.15			22.8	9.804	6	0.48	10.284	91.94	8.1
0.075			0.13	0.0559	45	3.6	3.66	95.60	4.4

Table 4- 5: Design Mix Proportions

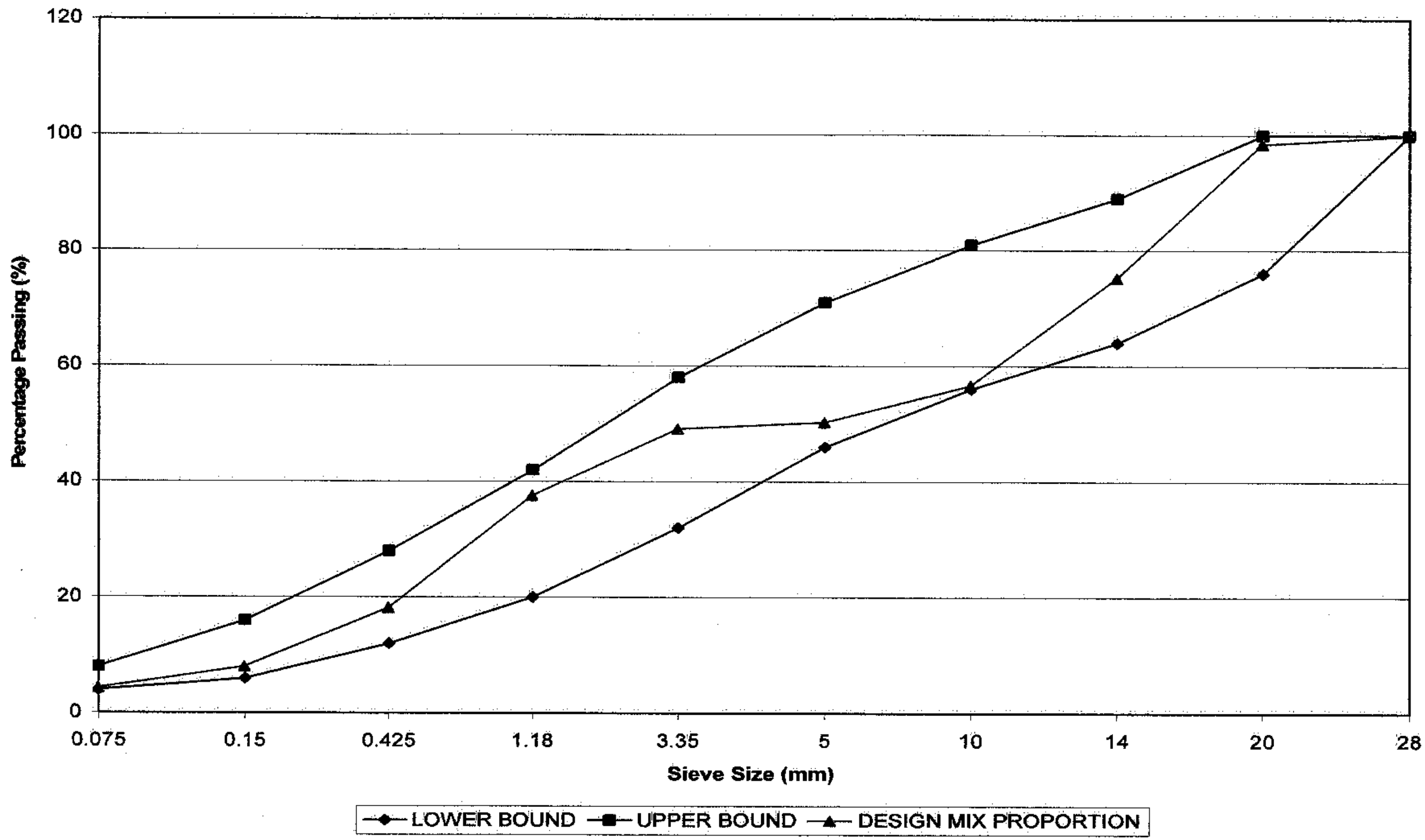


Figure 4- 4: Design Mix Proportion Curve

4.3 Marshall Stability Test

The research is now complete for the 1 to 3 percent of Rubber Modified Asphalt (RMA) mixtures. The specimens of the rubber mixtures are already being tested to find the porosity, stability and flow of each percentage of RMA mixture. Following are the results of the testing.

Table 4-6, **4-7**, and **4-8** show the values obtained for 1, 2 and 3 percent rubber content RMA varies from 4.5 to 6.5 percent binder content. The graphs of flow, stability, porosity and specific gravity versus the binder content for 1, 2, and 3 percent of rubber content RMA, were shown in **Figure 4-5** to **Figure 4-16**.

Table 4-9 shows the results of the Marshall Stability Test for the Conventional Mixtures using the Gyratory Machine, and also the graphs of flow, stability, porosity, and specific gravity versus the binder content, which is illustrated in **Figure 4-17** to **Figure 4-20**. The comparison of results between Conventional Mixtures and RMA is shown in **Table 4-10**. The results obtained for flow, stability, porosity, and specific gravity for all the RMA and conventional mixtures were shown in **Figure 4-21** to **Figure 4-24**.

The overall results for RMA and conventional mixtures shows the increasing value of air void, and flow, if using the RMA mixture, whereas the value of stability will be decrease, compare to the results obtained for conventional mixture.

4.3.1 Determination of Optimum Binder Content

Since the Marshall Stability Test is already completed for the Conventional Mixtures and Rubber Modified Asphalt Mixtures, the optimum binder content for all mixtures is determined.

For the 1 percent rubber content RMA, the optimum binder content obtained from the graphs of stability, and specific gravity are; **5.05%** and **5.80%**. So the average optimum binder content is **5.43%**. Refer to the graph of porosity, and flow, the optimum binder content of 5.43% give the porosity value of **12.0%** and flow value of **3.90 mm**. Based on the JKR Standard, the range of porosity for Conventional Mixture should be within 3 to 5 percent. Since the mixtures used additional materials of crumb rubber, it is accepted that the porosity will be slightly higher than the range for conventional mixture. Also the value of flow should be higher than 3 mm.

For the 2 percent rubber content RMA, the graphs of stability and specific gravity give the values of optimum binder content of; **5.50%** and **5.50%** respectively. So, the average optimum binder content is **5.50%** which gives the values of porosity and flow of **14.0%** and **4.38 mm** respectively. The values are accepted since it is higher than the range specified for the conventional mixture.

For the 3 percent rubber content RMA, the values of optimum binder content determine from the graphs of stability and specific gravity are; **5.48%** and **5.98%** respectively. The average optimum binder content obtained is **5.73%**. The corresponding values of porosity and flow obtained are **14.51%** and **4.65 mm** respectively. The values are also accepted for RMA mixtures.

The values of optimum binder content obtained for the Conventional Mixtures are **5.20%** from the graph of stability, and **5.50%** from the graph of specific gravity. The average optimum binder content is **5.35%**. Refer to the graph of porosity and flow versus the binder content, the values of porosity and flow are; **11.85%** and **3.38 mm** respectively. The porosity value should be between the ranges of 3 to 5 percent as specified by the JKR, but unfortunately, the result is out of the desired range. This could be due to the error from the Gyratory Machine. Similar test was performed several times and the same results were obtained. However, the values of porosity are expected to give insignificant effect to the pavement performance during Wheel Tracking and Beam Fatigue Test, since manual compaction is adopted in both tests. The value of flow obtained is accepted since it is still within the range stated by the JKR.

4.3.2 Analysis

From the results of optimum binder content obtained for all RMA mixtures (1 to 3 percent), and conventional mixture, it was found out that the optimum binder content require for RMA mixtures is higher as compared to the conventional mixtures. The optimum binder content for the RMA mixtures (1 to 3 percent) are **5.43%, 5.50%,** and **5.73%,** while the optimum binder content for the conventional mixture is **5.35%**. This again agreed with the findings of other researchers that RMA mixture required higher binder content.

The percentage of porosity obtained based on the optimum binder content also higher for rubber mixtures which is ranging from **12.0% to 14.51%**, compared only **11.85%** for the conventional mixtures. Previous research reported that air voids can be reduced if higher binder content is used. However, it is acceptable as the porosity should be higher if the binder content used is relatively lower.

The flow obtained for the rubber mixtures are **3.90 mm, 4.38 mm,** and **4.65 mm** respectively for 1 to 3 percent rubber content of RMA mixtures. The values are higher than the conventional mixtures which is only **3.38 mm**. Again it is expected that the flow obtained might relatively higher as compared to conventional mixtures.

From the results of stability and flow obtained from the Marshall Stability Test for RMA and conventional mixture, the **T-Test Two-Sample Assuming Equal Variances** has been done to find out the T-Stat values. The T-Test is using the 95% confidence level with 0.05 alpha values. The purpose of performing T-Test is to find out the significance and insignificance of two values. **Table 4-11** show the values of stability and flow for RMA and conventional mixture, whereas **Table 4-12** and **4-13** shows the T-Stat values obtained for stability and flow, when comparing the RMA mixture with conventional mixture.

For stability, the comparison between conventional and 1 percent rubber content of RMA mixtures give the T-Stat value of **1.146**, which is in between of the T-Critical Two-Tail value that is **2.306**. The T-Critical Two Tail value is the same for all comparison between conventional mixture and RMA mixture. Thus, the T-Stat value shows **no significance different** if the value is plotted in normal distribution graph, taking the T-Critical Two Tail value to be the negative and positive range. But for comparison between conventional and 2 percent of rubber content RMA mixture, there is **significance different** as the T-Stat value is **2.838** which are higher than the T Critical Two Tail value. It is the same for comparison between conventional and 3 percent of rubber content of RMA mixtures. The value of T-Stat is **6.298**, which shows significant difference. As the conclusion, the effect of scrapped rubber on pavement stability is not significant until the percent of rubber reach 3 percent.

For flow, the value of T-Stat for comparison of conventional and 1 percent rubber content of RMA mixtures is **-0.953**, which show significance difference in values, but for comparison between conventional and 2 percent of rubber content of RMA mixtures, show no significant difference as the T-Stat value is **-2.284**. The comparison between conventional and 3 percent rubber content of RMA mixture show the same result as the first comparison which is significant. The T-Stat value obtained is **-2.708**. For flow properties, it is clearly shown that added rubber has generally improved the flow properties of pavements.

The results of the T-Test indicate that there are different between the two values for both stability and flow.

Sample No.	Binder content by Mass of Mix (%)	Height (mm)	Mass of specimen		Volume (cm^3)	Specific Gravity		Air void (%)	Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	VMA		Measured	C.F	Corrected
1	4.5	69.9	1242.9	672.4	570.50	2.18	2.53	13.89	2.58	10.26	0.86	9.4
		69.53	1242.4	665.8	576.60	2.15	2.53	14.83	3.23	10.95	0.83	10.12
		67.68	1236.8	666.3	570.50	2.17	2.53	14.31	4.05	10.83	0.86	9.97
average			***1240.7***	***668.17***	***572.53***	***2.17***	***2.53***	***14.34***	***3.29***	***10.68***		***9.83***
2	5	67.56	1238.30	674.50	563.80	2.20	2.52	12.84	4.29	14.8	0.86	13.94
		67.16	1208.70	650.40	558.30	2.16	2.52	14.09	3.64	9.88	0.89	8.99
		68.03	1259.60	690.20	569.40	2.21	2.52	12.22	4.24	13.06	0.86	12.2
average			***1235.53***	***671.70***	***563.83***	***2.19***	***2.52***	***13.05***	***4.06***	***12.58***		***11.71***
3	5.5	68.64	1248.90	679.20	569.70	2.19	2.50	12.31	4.16	10.69	0.86	9.83
		67.77	1242.10	680.40	561.70	2.21	2.50	11.55	2.87	11.67	0.86	10.81
		68.35	1259.30	690.10	569.20	2.21	2.50	11.50	3.44	12.14	0.86	11.28
average			***1250.10***	***683.23***	***566.87***	***2.21***	***2.50***	***11.79***	***3.49***	***11.50***		***10.64***
4	6	67.26	1239.10	678.10	561.00	2.21	2.48	10.94	3.87	9.59	0.86	8.73
		67.54	1243.60	678.70	564.90	2.20	2.48	11.23	4.39	10.17	0.86	9.31
		69.14	1266.00	693.10	572.90	2.21	2.48	10.89	4.44	10.85	0.86	9.99
average			***1249.57***	***683.30***	***566.27***	***2.21***	***2.48***	***11.02***	***4.23***	***10.20***		***9.34***
5	6.5	68.30	1252.20	682.50	569.70	2.20	2.46	10.65	4.11	9.36	0.86	8.5
		69.40	1269.30	691.10	578.20	2.20	2.46	10.76	5.64	9.19	0.83	8.36
		68.43	1253.20	682.50	570.70	2.20	2.46	10.74	4.29	8.5	0.86	7.64
average			***1258.23***	***685.37***	***572.87***	***2.20***	***2.46***	***10.72***	***4.68***	***9.02***		***8.17***

Table 4- 6: Results of Marshall Stability Test for 1% RMA Mixture

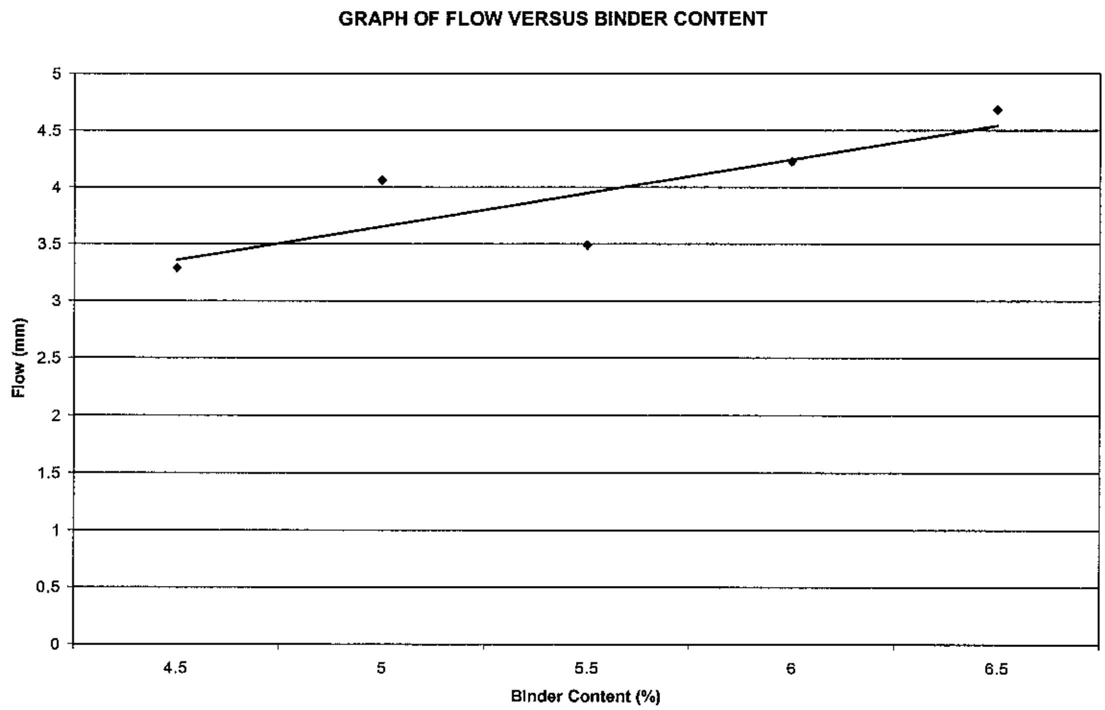


Figure 4- 5: Graph of Flow versus Binder Content (1% RMA)

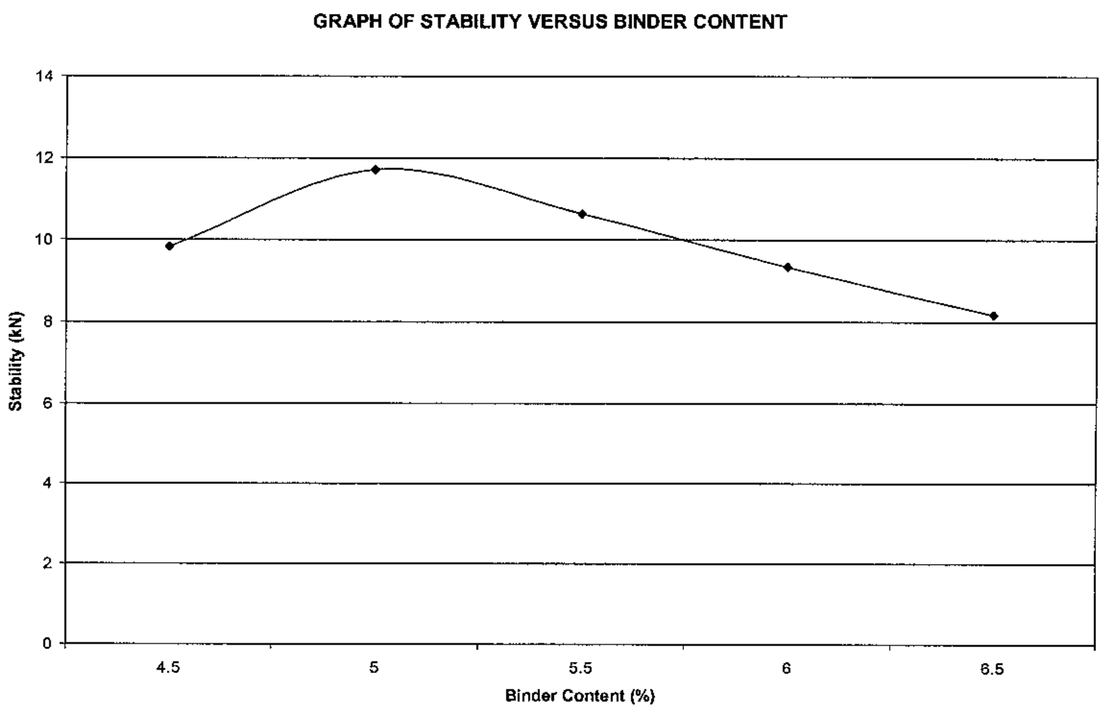


Figure 4- 6: Graph of Stability versus Binder Content (1% RMA)

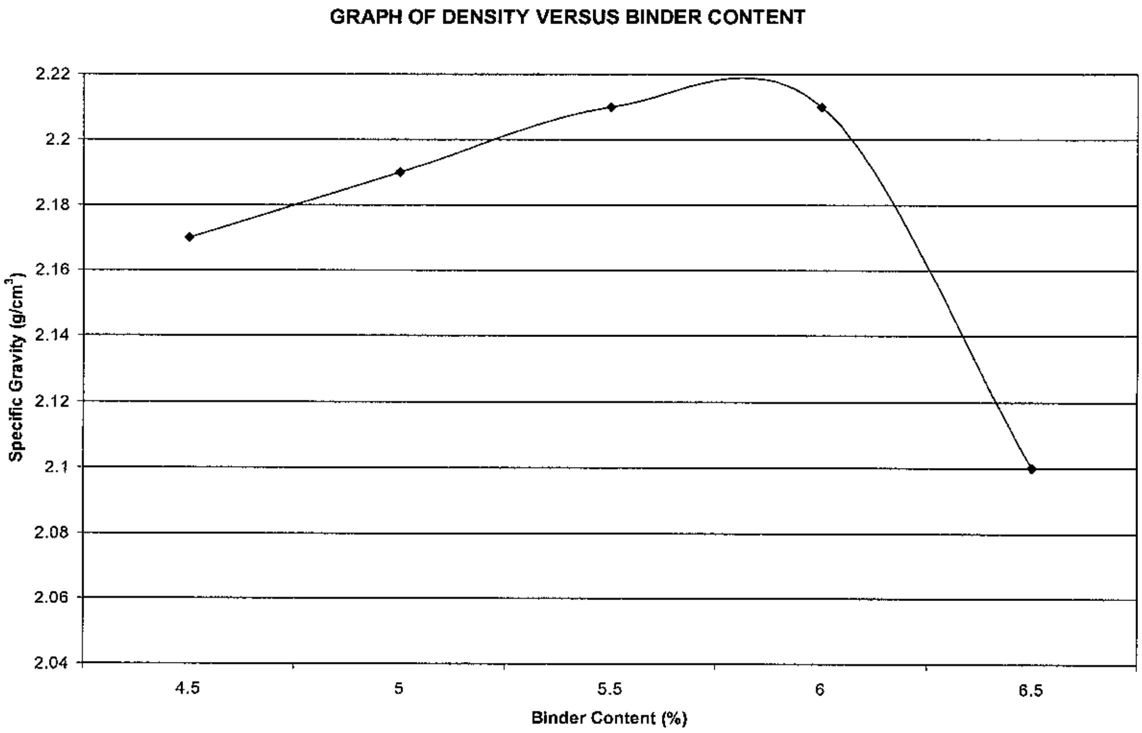


Figure 4- 7: Graph of Specific Gravity versus Binder Content (1% RMA)

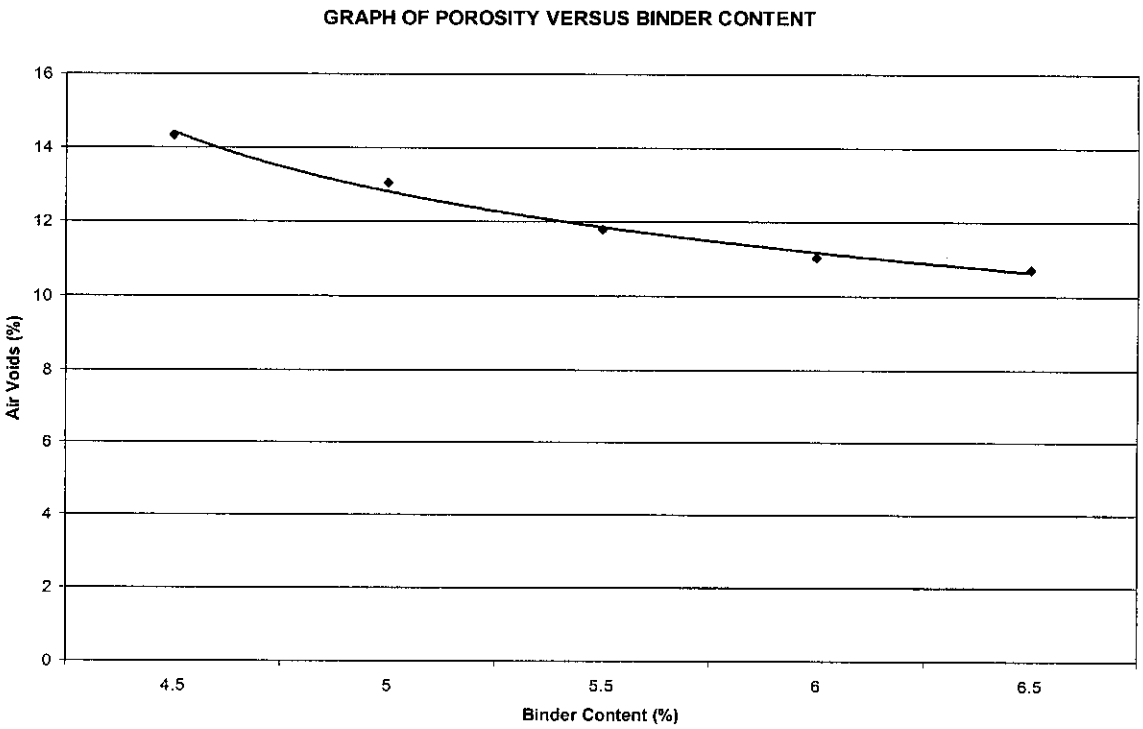


Figure 4- 8: Graph of Porosity versus Binder Content (1% RMA)

Sample No.	Binder content by Mass of Mix (%)	Height (mm)	Mass of specimen		Volume (cm^3)	Specific Gravity		Air void (%)	Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	VMA		Measured	C.F	Corrected
1	4.5	69.80	1249.30	658.60	590.70	2.11	2.53	16.41	4.35	10.56	0.81	9.75
		69.14	1253.00	661.50	591.50	2.12	2.53	16.27	4.06	9.55	0.81	8.74
		67.73	1231.90	647.60	584.30	2.11	2.53	16.67	4.28	9.53	0.83	8.7
average			***1244.73***	***655.90***	***588.83***	***2.11***	***2.53***	***16.45***	***4.23***	***9.88***		***9.06***
2	5	69.68	1238.40	657.20	581.20	2.13	2.52	15.45	4.83	9.23	0.83	8.4
		67.69	1239.40	671.00	568.40	2.18	2.52	13.47	4.14	12.71	0.86	11.85
		68.43	1260.70	682.40	578.30	2.18	2.52	13.49	3.87	10.32	0.83	9.49
average			***1246.17***	***670.20***	***575.97***	***2.16***	***2.52***	***14.14***	***4.28***	***10.75***		***9.91***
3	5.5	67.59	1224.00	658.30	565.70	2.16	2.50	13.45	4.71	9.37	0.86	8.51
		68.80	1251.40	683.10	568.30	2.20	2.50	11.92	3.69	11.15	0.86	10.29
		68.61	1263.80	685.30	578.50	2.18	2.50	12.62	4.06	10.31	0.83	9.48
average			***1253.07***	***675.57***	***570.83***	***2.18***	***2.50***	***12.66***	***4.15***	***10.28***		***9.43***
4	6	68.30	1249.40	664.50	584.90	2.14	2.48	13.87	6.13	7.94	0.83	7.11
		69.18	1265.80	684.40	581.40	2.18	2.48	12.21	4.06	9.81	0.83	8.98
		68.52	1251.80	676.10	575.70	2.17	2.48	12.32	4.06	8.77	0.83	7.94
average			***1255.67***	***675.00***	***580.67***	***2.16***	***2.48***	***12.80***	***4.75***	***8.84***		***8.01***
5	6.5	68.92	1257.80	678.80	579.00	2.17	2.46	11.69	4.94	11.64	0.83	10.81
		68.01	1242.00	671.00	571.00	2.18	2.46	11.58	4.77	10.41	0.86	9.55
		68.85	1240.50	666.90	573.60	2.16	2.46	12.09	5.01	8.01	0.86	7.15
average			***1246.77***	***672.23***	***574.53***	***2.17***	***2.46***	***11.79***	***4.91***	***10.02***		***9.17***

Table 4- 7: Results of Marshall Stability Test for 2% RMA Mixture

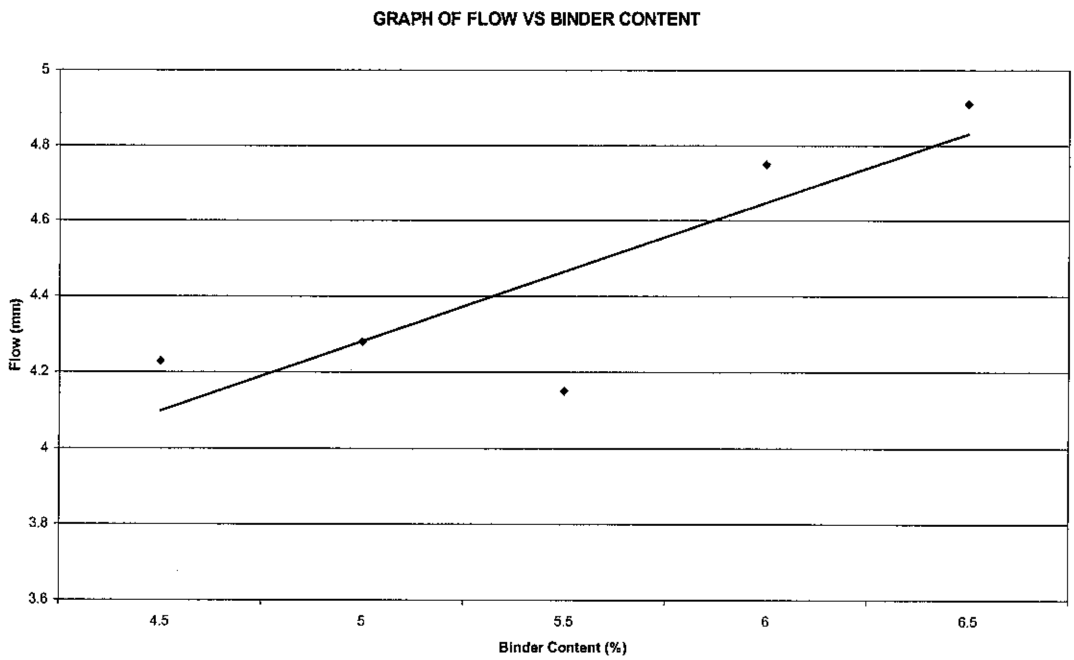


Figure 4- 9: Graph of Flow versus Binder Content (2% RMA)

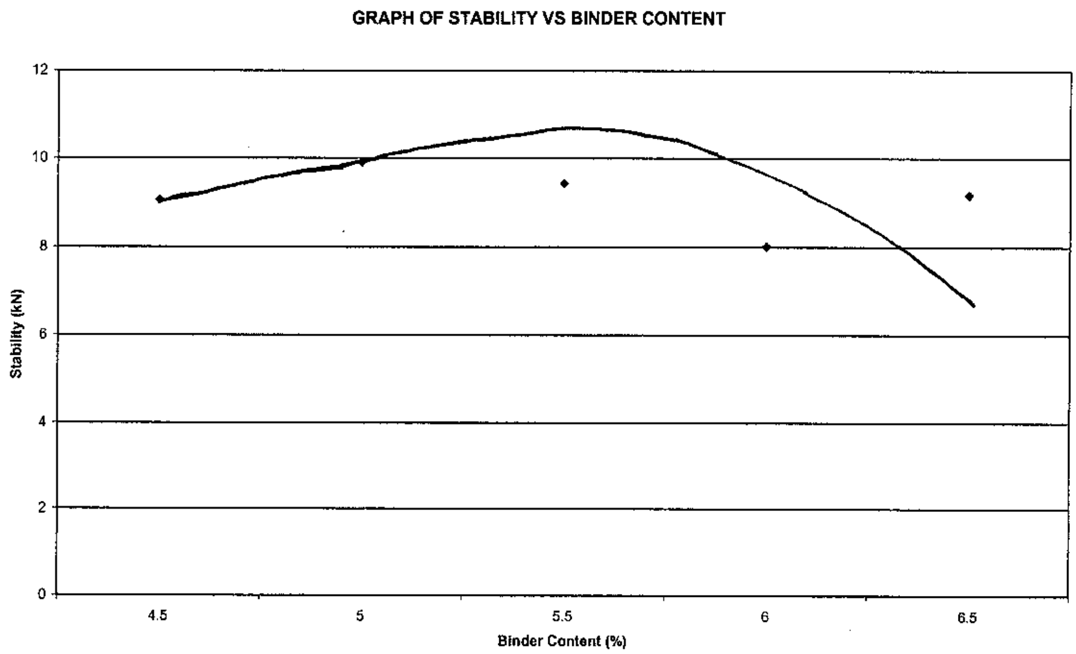


Figure 4- 10: Graph of Stability versus Binder Content (2% RMA)

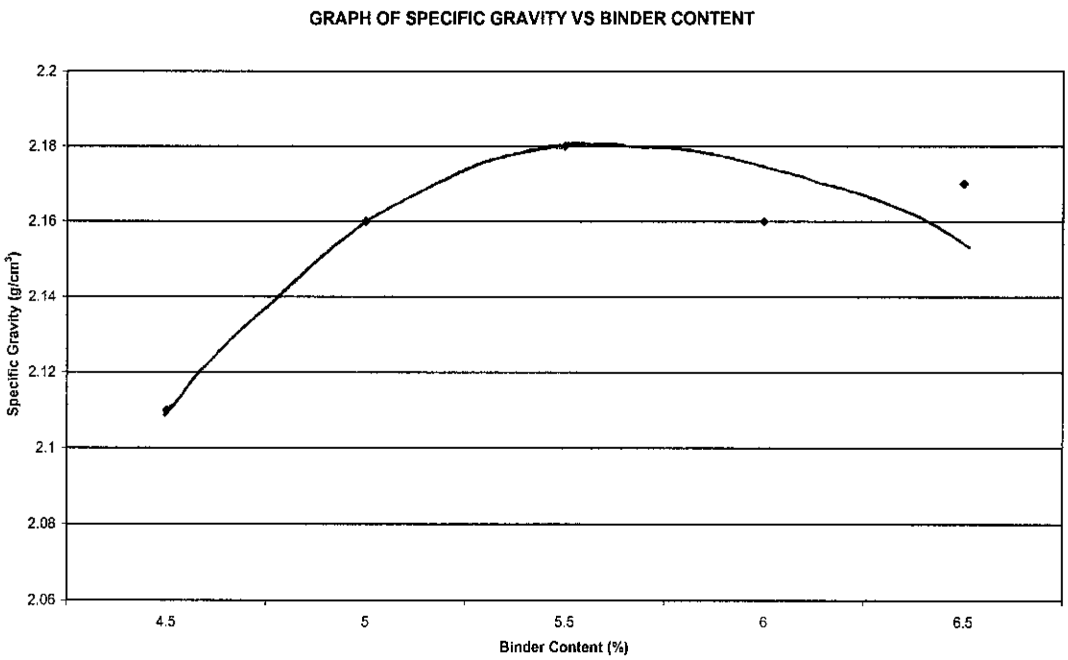


Figure 4- 11: Graph of Specific Gravity versus Binder Content (2% RMA)

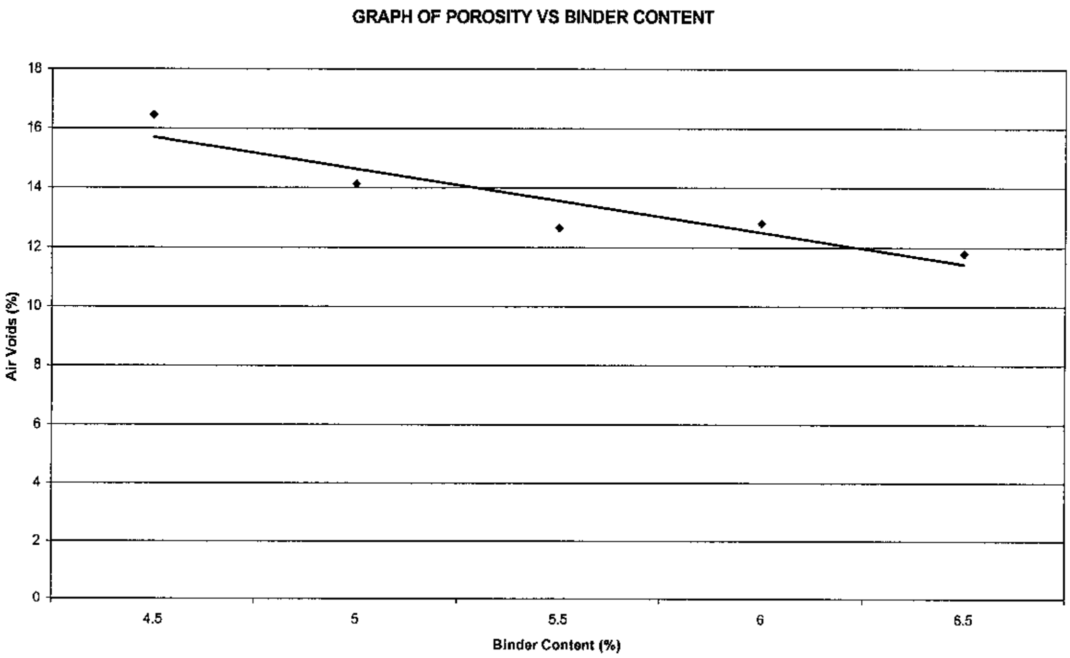


Figure 4- 12: Graph of Porosity versus Binder Content (2% RMA)

Sample no.	Binder content by Mass of Mix (%)	Height (mm)	Mass of specimen		Volume (cm^3)	Specific Gravity		Air void (%)	Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	VMA		Measured	C.F	Corrected
1	4.5	69.57	1246.40	655.0	591.40	2.11	2.53	16.70	4.99	9.19	0.81	8.38
		69.03	1238.30	647.1	591.20	2.09	2.53	17.21	5.01	9.13	0.81	8.32
		69.86	1234.50	639.9	594.60	2.08	2.53	17.94	4.66	7.74	0.81	6.93
average			***1239.73***	***647.3***	***592.40***	***2.09***	***2.53***	***17.28***	***4.89***	***8.69***		***7.88***
2	5	69.15	1233.20	644.00	589.20	2.09	2.52	16.94	4.29	6.51	0.81	5.70
		69.24	1242.90	652.60	590.30	2.11	2.52	16.45	3.99	5.76	0.81	4.95
		69.24	1235.80	643.00	592.80	2.08	2.52	17.27	3.99	5.99	0.81	5.18
average			***1237.30***	***646.53***	***590.77***	***2.09***	***2.52***	***16.89***	***4.09***	***6.09***		***5.28***
3	5.5	68.81	1249.20	657.90	591.30	2.11	2.50	15.49	5.36	6.74	0.81	5.93
		69.59	1253.40	665.40	588.00	2.13	2.50	14.73	4.17	6.43	0.81	5.62
		70.02	1256.80	660.70	596.10	2.11	2.50	15.67	4.46	6.66	0.81	5.85
average			***1253.13***	***661.33***	***591.80***	***2.12***	***2.50***	***15.30***	***4.66***	***6.61***		***5.80***
4	6	68.12	1233.60	645.50	588.10	2.10	2.48	15.42	5.07	5.74	0.81	4.93
		69.15	1253.00	660.40	592.60	2.11	2.48	14.74	4.53	7.44	0.81	6.63
		68.31	1241.40	660.80	580.60	2.14	2.48	13.78	4.36	7.67	0.83	6.84
average			***1242.67***	***655.57***	***587.10***	***2.12***	***2.48***	***14.65***	***4.65***	***6.95***		***6.13***
5	6.5	68.46	1243.90	669.70	574.20	2.17	2.46	11.94	4.65	8.65	0.83	7.82
		69.37	1259.30	677.40	581.90	2.16	2.46	12.03	5.35	7.94	0.83	7.11
		69.08	1252.50	670.70	581.80	2.15	2.46	12.49	4.65	7.15	0.83	6.32
average			***1251.90***	***672.60***	***579.30***	***2.16***	***2.46***	***12.15***	***4.88***	***7.91***		***7.08***

Table 4- 8: Results of Marshall Stability Test for 3% RMA Mixture

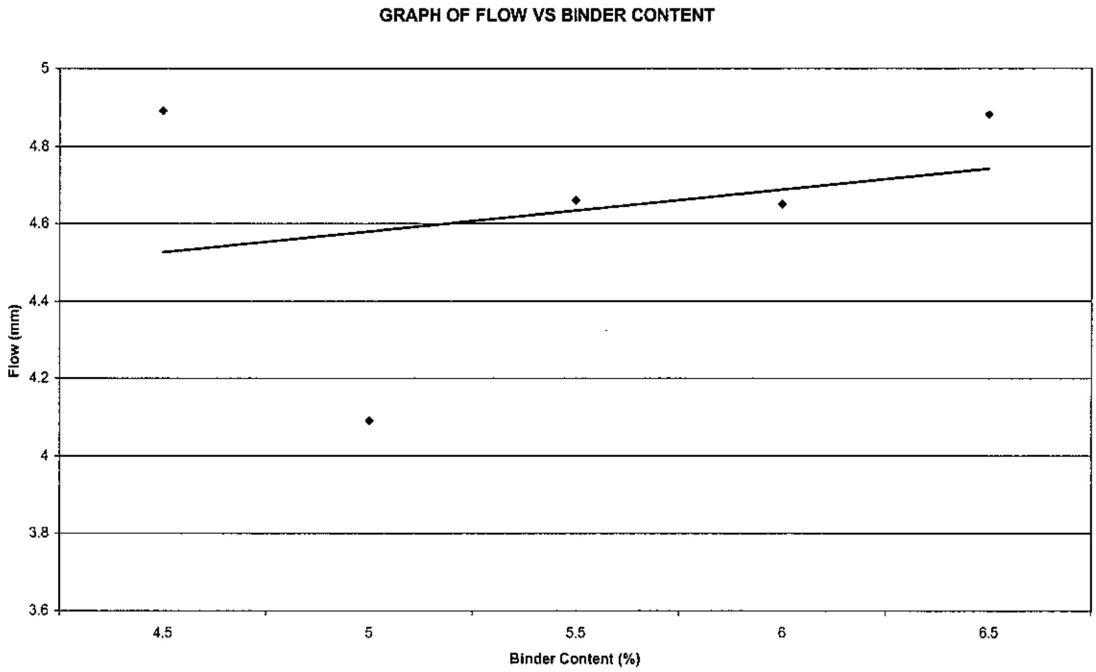


Figure 4- 13: Graph of Flow versus Binder Content (3% RMA)

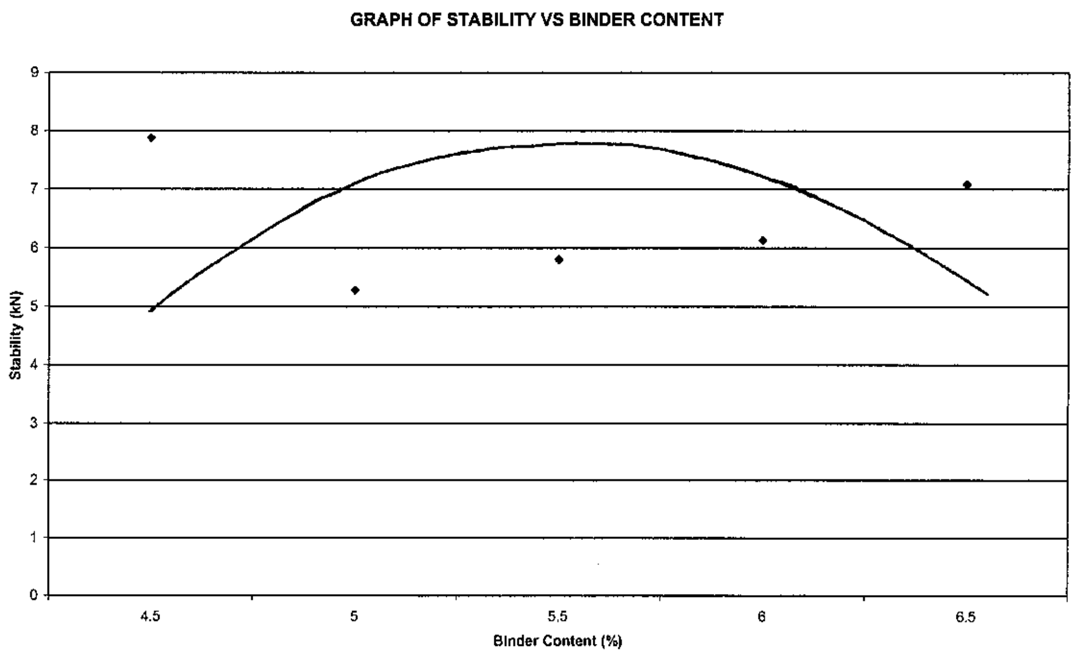


Figure 4- 14: Graph of Stability versus Binder Content (3% RMA)

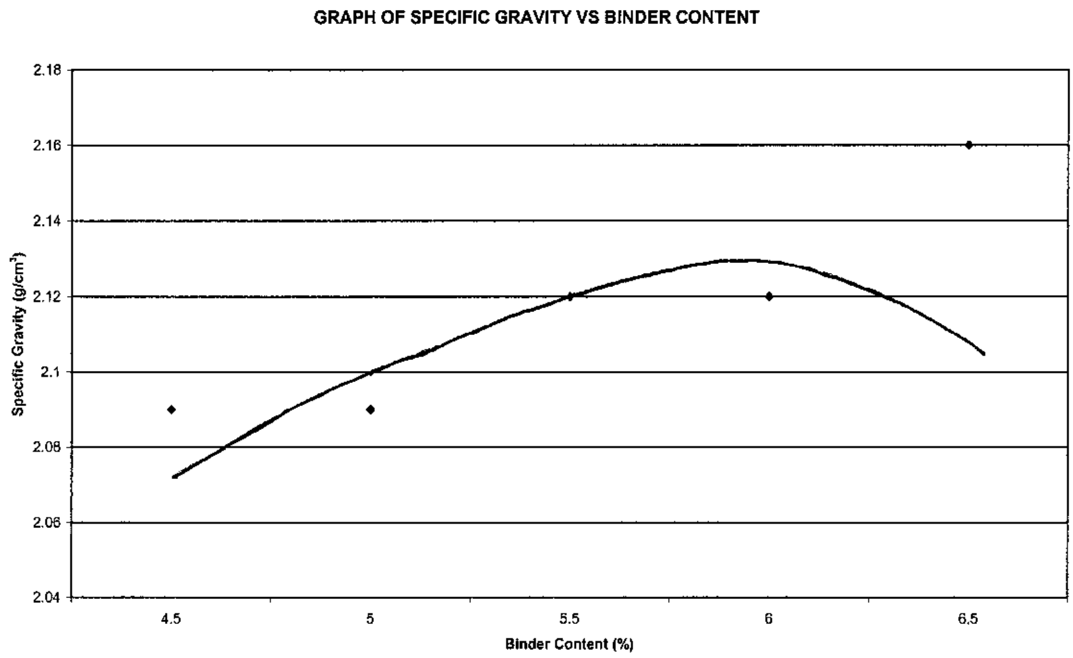


Figure 4- 15: Graph of Specific Gravity versus Binder Content (3% RMA)

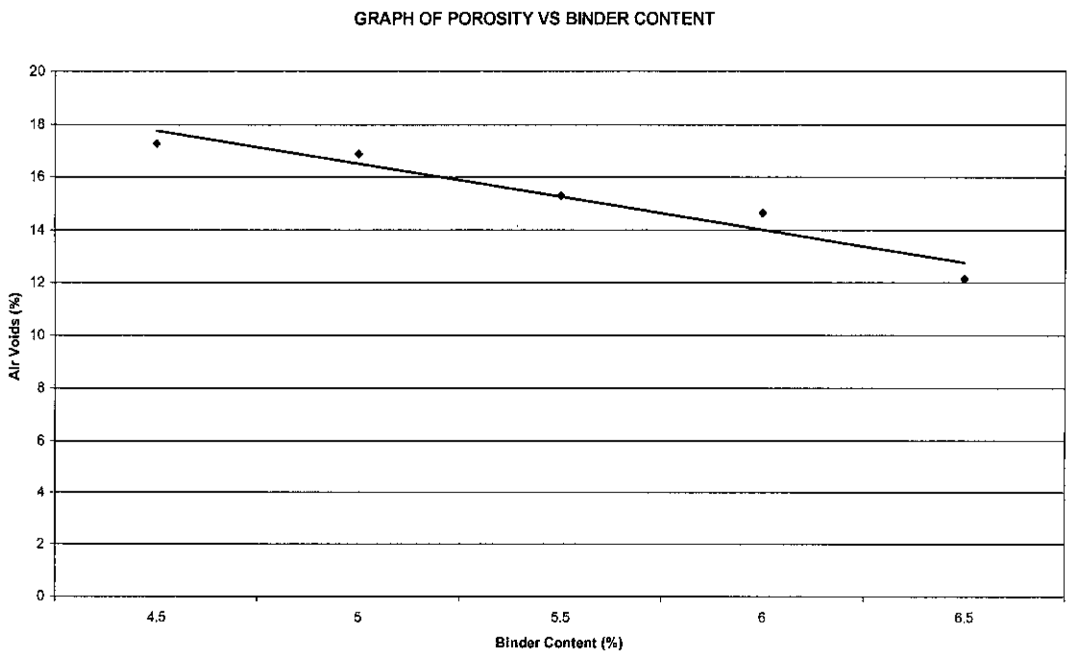


Figure 4- 16: Graph of Porosity versus Binder Content (3% RMA)

Sample No.	Binder content by Mass of Mix (%)	Height (mm)	Mass of specimen		Volume (cm^3)	Specific Gravity		Air void (%)	Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	VMA		Measured	C.F	Corrected
1	4.5	68.30	1231.90	671.60	560.30	2.20	2.53	13.10	2.39	13.59	0.89	12.70
		68.30	1234.50	672.70	561.80	2.20	2.53	13.15	2.99	13.93	0.89	13.04
		69.67	1248.70	679.70	569.00	2.19	2.53	13.26	2.64	10.99	0.86	10.13
average			***1238.37***	***674.67***	***563.70***	***2.20***	***2.53***	***13.17***	***2.67***	***12.84***		***11.96***
2	5	68.13	1250.50	687.40	563.10	2.22	2.52	11.88	3.22	14.37	0.86	13.51
		69.20	1246.20	677.70	568.50	2.19	2.52	13.01	3.17	11.60	0.86	10.74
		67.74	1240.20	680.40	559.80	2.22	2.52	12.09	2.64	12.29	0.86	11.43
average			***1245.63***	***681.83***	***563.80***	***2.21***	***2.52***	***12.32***	***3.01***	***12.75***		***11.89***
3	5.5	68.23	1255.70	687.40	568.30	2.21	2.50	11.62	3.29	12.19	0.86	11.33
		68.26	1256.00	688.40	567.60	2.21	2.50	11.49	3.33	12.52	0.78	11.74
		68.82	1262.30	691.10	571.20	2.21	2.50	11.60	3.02	10.86	0.83	10.03
average			***1258.00***	***688.97***	***569.03***	***2.21***	***2.50***	***11.57***	***3.21***	***11.86***		***11.03***
4	6	68.58	1259.30	691.00	568.30	2.22	2.48	10.65	3.33	11.60	0.86	10.74
		69.16	1265.10	691.20	573.90	2.20	2.48	11.11	3.88	10.55	0.86	9.69
		69.34	1267.90	692.90	575.00	2.21	2.48	11.09	4.04	10.80	0.83	9.97
average			***1264.10***	***691.70***	***572.40***	***2.21***	***2.48***	***10.95***	***3.75***	***10.98***		***10.13***
5	6.5	67.55	1242.60	681.10	561.50	2.21	2.46	10.04	4.46	9.56	0.86	8.70
		67.26	1237.00	674.00	563.00	2.20	2.46	10.68	4.26	10.72	0.86	9.86
		70.18	1286.70	700.10	586.60	2.19	2.46	10.83	5.99	9.96	0.83	9.13
average			***1255.43***	***685.07***	***570.37***	***2.20***	***2.46***	***10.52***	***4.90***	***10.08***		***9.23***

Table 4- 9: Results of Marshall Stability Test for Conventional Mixture

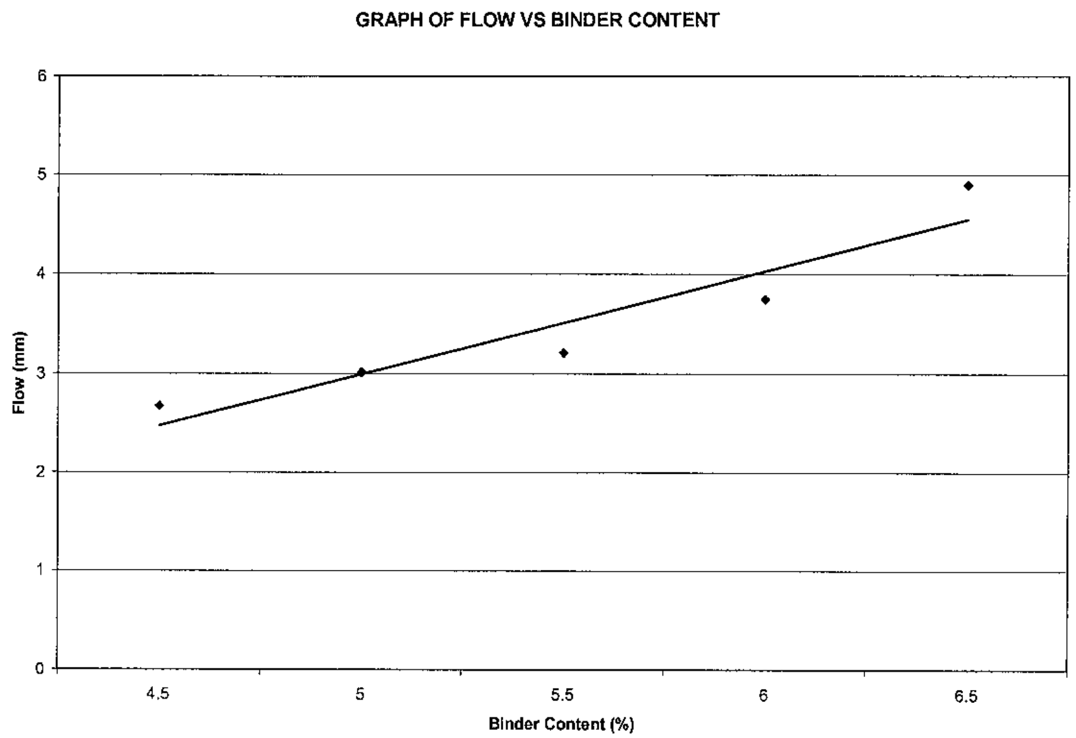


Figure 4- 17: Graph of Flow versus Binder Content

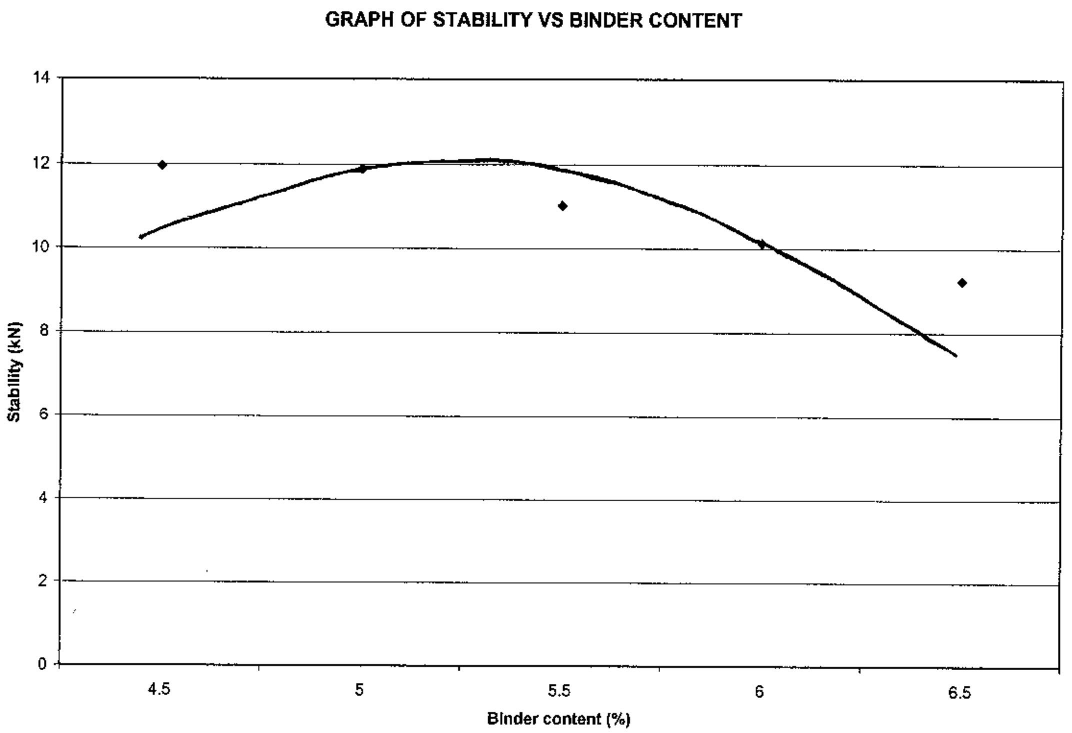


Figure 4- 18: Graph of Stability versus Binder Content

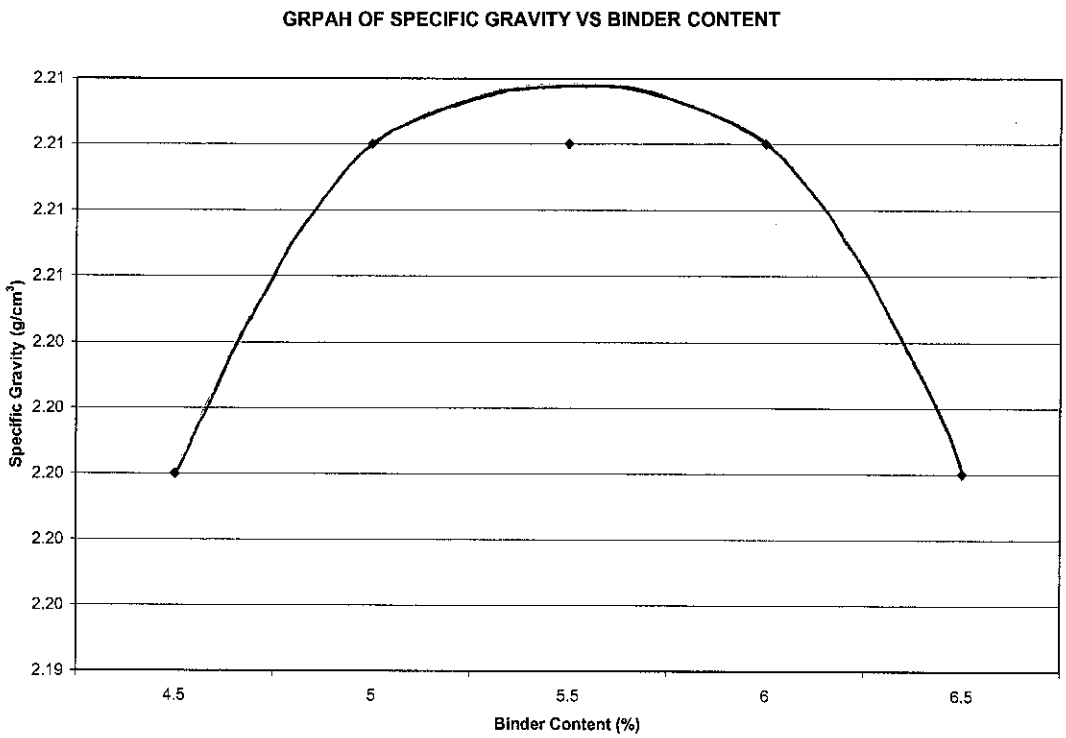


Figure 4- 19: Graph of Specific Gravity versus Binder Content

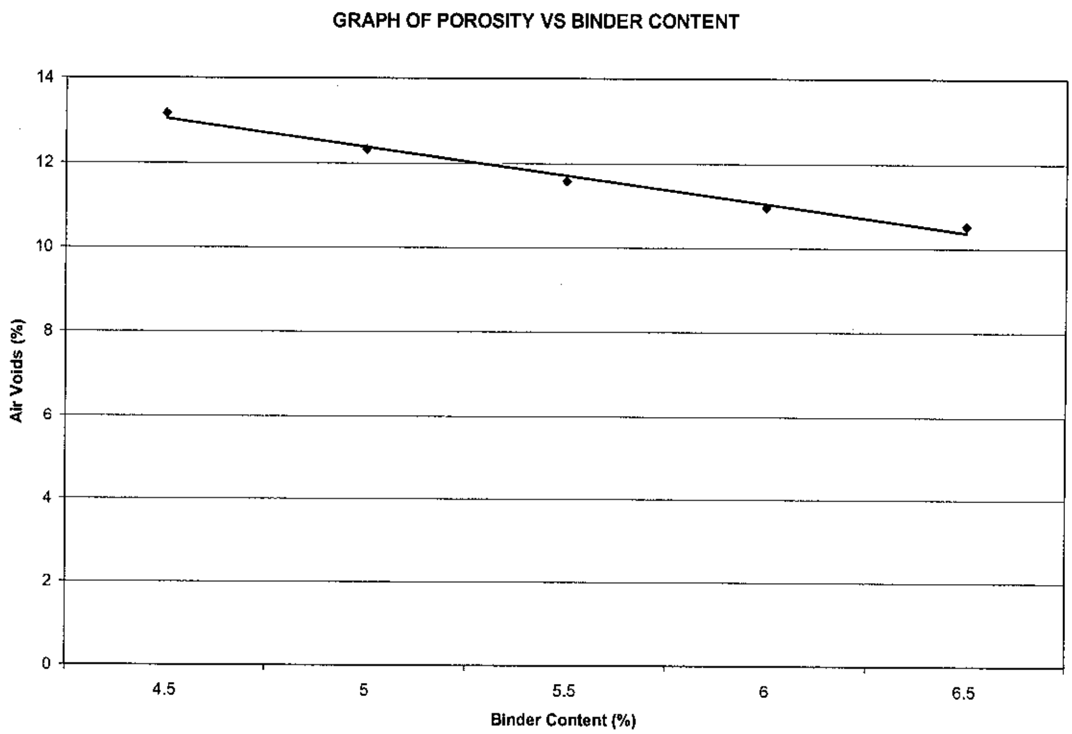


Figure 4- 20: Graph of Porosity versus Binder Content

BINDER CONTENT	STANDARD				RUBBER 1%			
	FLOW	STABILITY	POROSITY	SPECIFIC GRAVITY	FLOW	STABILITY	POROSITY	SPECIFIC GRAVITY
4.5	2.67	11.96	13.17	2.20	3.29	9.83	14.34	2.17
5	3.01	11.89	12.32	2.21	4.06	11.71	13.05	2.19
5.5	3.21	11.03	11.57	2.21	3.49	10.64	11.79	2.21
6	3.75	10.13	10.95	2.21	4.23	9.34	11.02	2.21
6.5	4.90	9.23	10.52	2.20	4.68	8.17	10.72	2.20

BINDER CONTENT	STANDARD				RUBBER 2%			
	FLOW	STABILITY	POROSITY	SPECIFIC GRAVITY	FLOW	STABILITY	POROSITY	SPECIFIC GRAVITY
4.5	2.67	11.96	13.17	2.20	4.23	9.06	16.45	2.11
5	3.01	11.89	12.32	2.21	4.28	9.91	14.14	2.16
5.5	3.21	11.03	11.57	2.21	4.15	9.43	12.66	2.18
6	3.75	10.13	10.95	2.21	4.75	8.01	12.80	2.16
6.5	4.90	9.23	10.52	2.20	4.91	9.17	11.79	2.17

BINDER CONTENT	STANDARD				RUBBER 3%			
	FLOW	STABILITY	POROSITY	SPECIFIC GRAVITY	FLOW	STABILITY	POROSITY	SPECIFIC GRAVITY
4.5	2.67	11.96	13.17	2.20	4.89	7.88	17.28	2.09
5	3.01	11.89	12.32	2.21	4.09	5.28	16.89	2.09
5.5	3.21	11.03	11.57	2.21	4.66	5.80	15.30	2.12
6	3.75	10.13	10.95	2.21	4.65	6.13	14.65	2.12
6.5	4.90	9.23	10.52	2.20	4.88	7.08	12.15	2.16

Table 4- 10: Comparison of Marshall Test Results between Conventional and RMA Mixture

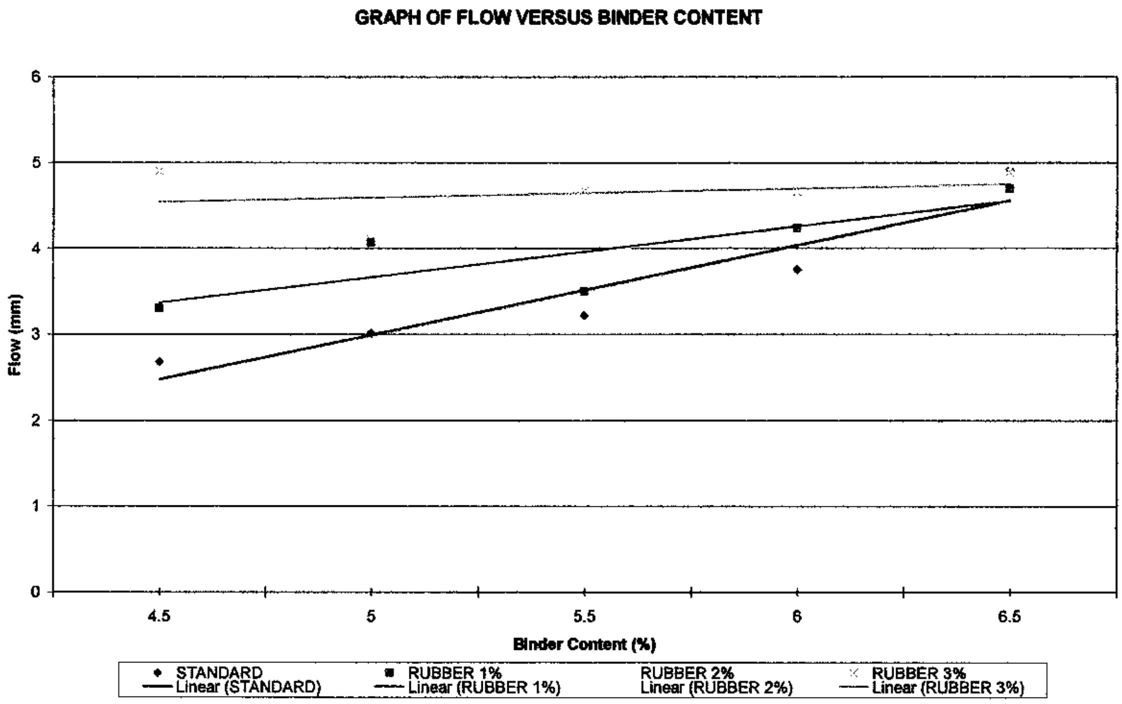


Figure 4- 21: Graph of Flow versus Binder Content (All)

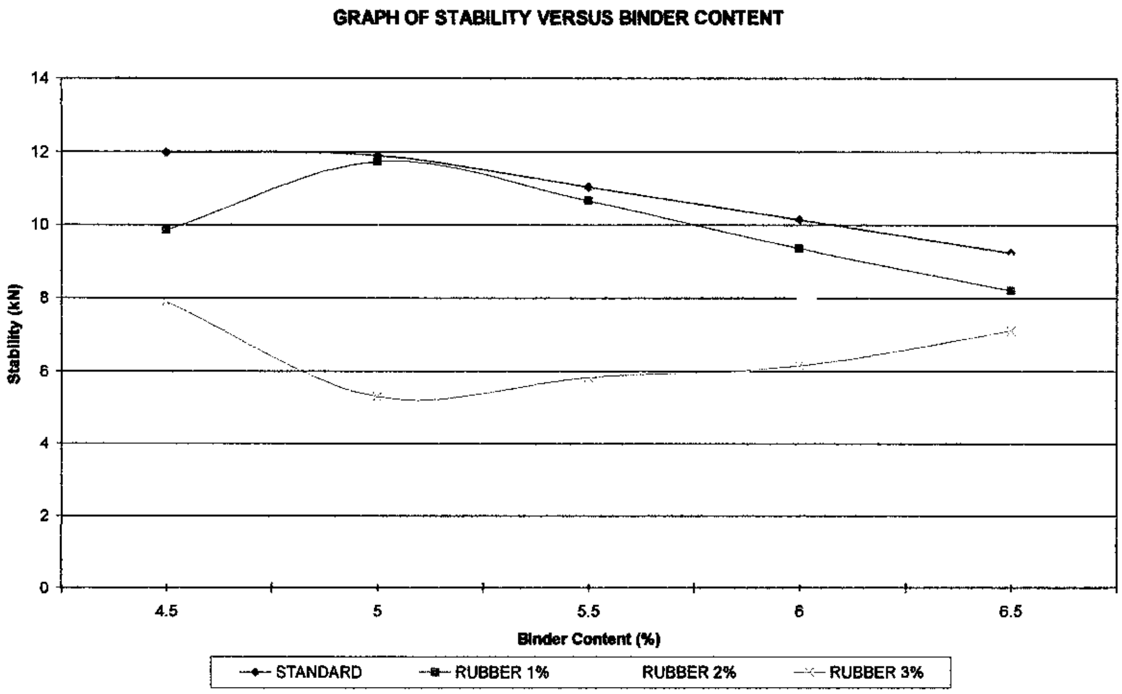


Figure 4- 22: Graph of Stability versus Binder Content (All)

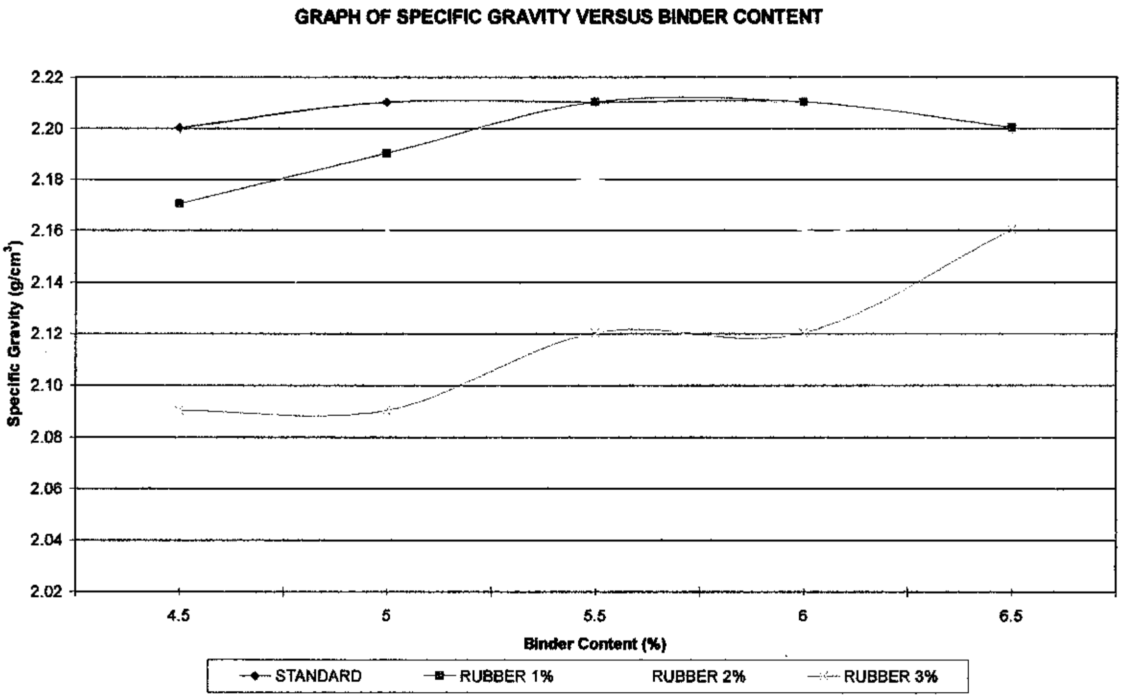


Figure 4- 23: Graph of Specific Gravity versus Binder Content (All)

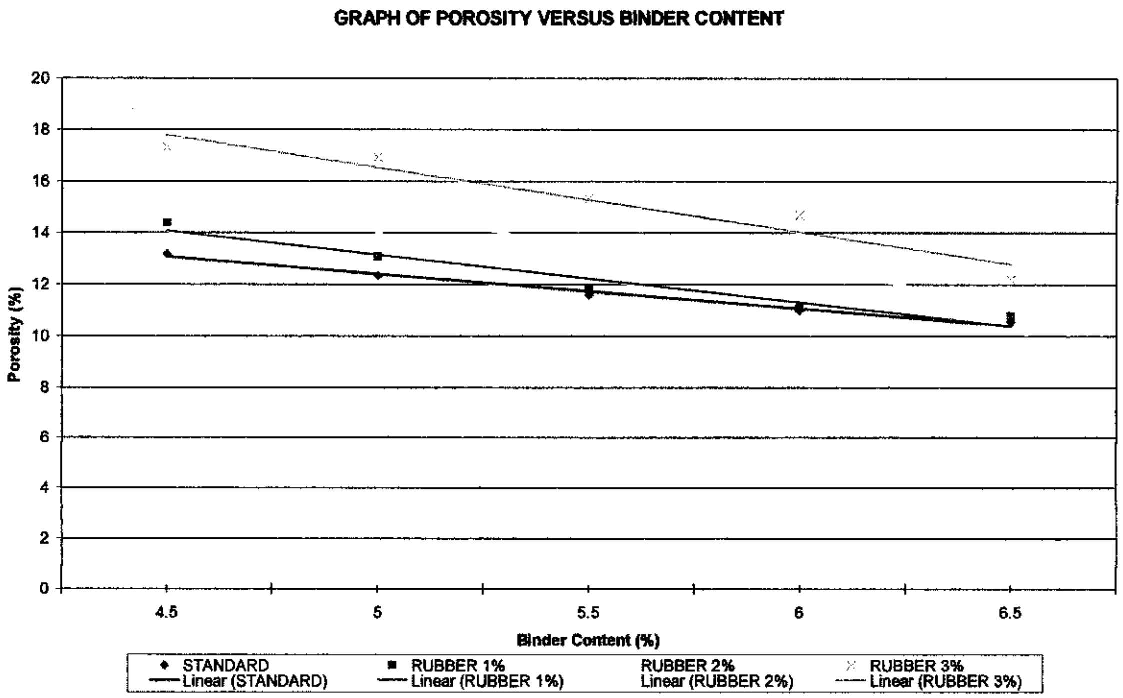


Figure 4- 24: Graph of Porosity versus Binder Content (All)

BINDER CONTENT	CONVENTIONAL		1% RMA	
	FLOW	STABILITY	FLOW	STABILITY
4.5	2.67	11.96	3.29	9.83
5	3.01	11.89	4.06	11.71
5.5	3.21	11.03	3.49	10.64
6	3.75	10.13	4.23	9.34
6.5	4.90	9.23	4.68	8.17

BINDER CONTENT	CONVENTIONAL		2% RMA	
	FLOW	STABILITY	FLOW	STABILITY
4.5	2.67	11.96	4.23	9.06
5	3.01	11.89	4.28	9.91
5.5	3.21	11.03	4.15	9.43
6	3.75	10.13	4.75	8.01
6.5	4.90	9.23	4.91	9.17

BINDER CONTENT	CONVENTIONAL		3% RMA	
	FLOW	STABILITY	FLOW	STABILITY
4.5	2.67	11.96	4.89	7.88
5	3.01	11.89	4.09	5.28
5.5	3.21	11.03	4.66	5.80
6	3.75	10.13	4.65	6.13
6.5	4.90	9.23	4.88	7.08

Table 4- 11: Results of Marshall Test for Flow and Stability (Conventional and RMA Mixture)

	CONVENTIONAL	**_1% RMA_**
Mean	10.848	9.938
Variance	1.372	1.782
Observations	5	5
Pooled Variance	1.577	
Hypothesized Mean Difference	0	
df	8	
t Stat	1.146	
P(T<=t) one-tail	0.143	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.285	
t Critical two-tail	2.31	

	CONVENTIONAL	**_2% RMA_**
Mean	10.848	9.116
Variance	1.372	0.490
Observations	5	5
Pooled Variance	0.931	
Hypothesized Mean Difference	0	
df	8	
t Stat	2.838	
P(T<=t) one-tail	0.011	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.022	
t Critical two-tail	2.306	

	CONVENTIONAL	**_3% RMA_**
Mean	10.848	6.434
Variance	1.372	1.084
Observations	5	5
Pooled Variance	1.228	
Hypothesized Mean Difference	0	
df	8	
t Stat	6.298	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.00023	
t Critical two-tail	2.306	

Table 4- 12: Results of T-Test Two Sample Assuming Equal Variance for Stability

	CONVENTIONAL	*1% RMA*
Mean	3.508	3.95
Variance	0.759	0.318
Observations	5	5
Pooled Variance	0.538	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.953	
P(T<=t) one-tail	0.184	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.369	
t Critical two-tail	2.306	

	CONVENTIONAL	*2% RMA*
Mean	3.508	4.464
Variance	0.759	0.117
Observations	5	5
Pooled Variance	0.438	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.284	
P(T<=t) one-tail	0.026	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.052	
t Critical two-tail	2.306	

	CONVENTIONAL	*3% RMA*
Mean	3.508	4.634
Variance	0.759	0.106
Observations	5	5
Pooled Variance	0.432	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.708	
P(T<=t) one-tail	0.013	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.027	
t Critical two-tail	2.306	

Table 4- 13: Results of T-Test Two Sample Assuming Equal Variance for Flow

4.4 Wheel Tracking Test

The Wheel Tracking Test for conventional mixture and Rubber Modified Asphalt (RMA) mixture are successfully completed. Two samples have been prepared, which are; one sample for conventional mixture and one sample for RMA mixture. The percentage of rubber particles used for RMA mixture is **3 percent**. The highest percentage of rubber particles is used as to find out the maximum performance that the RMA mixture can give. Assume that the more rubber particles used the better result it will give.

The purpose of performing the Wheel Tracking Test is to find the maximum cycles the specimen can withstand before the sample is fail. From the experiment that have been done for the conventional mixture, the maximum rut depth for **45 minutes** of cyclic loading to fail, is **12.6 mm**. **Figure 4-25** shows the graph of rut depth versus time for both conventional mixture and RMA mixture. Both graphs show the rutting depth is increase as the time increasing. The test is running for 45 minutes which is set as the constraint in the experiment.

The rut depth created by RMA mixture is less compared to one created by conventional mixture, which is **9.8 mm**. The rut depth is lessened about **22.2%**. So, it can be conclude here that the RMA mixture is more resistant to rutting. There is an improvement in resistant to permanent deformation and thus it is expected the pavement life is extended. The decreasing of the rut depth for RMA mixture is expected due to the elasticity properties of the rubber. Elasticity means that rubber are springly and compressible under load; usually they return to shape or "rebound" when the load is removed, although some residual deformation may occur after repeated load repetitions. Thus, it enhances the resistance to permanent deformation.

The result obtained from the Wheel Tracking Test has achieved the objective in improving the permanent deformation of pavement. Thus, in can be concludes that introducing rubber in asphalt mixture can improve the resistance of asphalt pavement against deformation.

TIME (minute)	TEMPERATURE (°C)		RUT DEPTH (mm)	
	CONVENTIONAL MIXTURE	RMA MIXTURE	CONVENTIONAL MIXTURE	RMA MIXTURE
0	46.9	45.8	0.0	0.0
1	46.9	45.8	0.4	0.0
2	46.7	45.9	0.8	0.5
3	46.7	45.9	1.3	0.8
4	46.6	45.9	1.7	1.1
5	46.4	45.9	2.1	1.5
6	46.4	45.9	2.3	1.9
7	46.1	45.9	2.5	2.1
8	46.1	45.9	3.0	2.4
9	46.0	46.0	3.3	2.9
10	45.8	46.0	3.7	3
11	45.7	45.9	4.1	3.2
12	45.8	45.9	4.4	3.5
13	45.5	46.0	4.8	3.6
14	45.6	46.1	5.1	4.1
15	45.6	46.1	5.4	4.6
16	45.2	46.1	5.6	5.0
17	45.0	46.0	5.8	5.2
18	44.9	46.0	6.1	5.6
19	44.7	46.0	6.4	5.9
20	44.6	45.9	6.5	6.2
21	44.5	45.9	6.6	6.4
22	44.4	45.8	6.7	6.5
23	44.3	45.9	6.9	6.7
24	44.7	46.0	7.1	6.9
25	45.5	46.0	7.3	6.9
26	46.2	45.9	7.4	7.1
27	46.5	45.9	7.7	7.2
28	46.4	46.0	8.0	7.4
29	46.3	46.0	8.3	7.6
30	46.2	46.0	8.4	7.7
31	46.0	46.0	8.8	7.9
32	45.8	45.9	9.0	8.0
33	45.7	46.0	9.3	8.1
34	45.4	46.0	9.6	8.3
35	45.1	46.0	9.8	8.5
36	45.0	46.0	10.3	8.6
37	44.9	45.9	10.5	8.7
38	44.7	45.9	10.6	9.0
39	44.6	45.9	11.0	9.1
40	44.4	45.9	11.4	9.3
41	44.3	45.9	11.9	9.4
42	44.2	45.7	12.0	9.6
43	44.9	45.9	12.2	9.6
44	45.2	45.9	12.4	9.8
45	45.5	45.9	12.6	9.8

Table 4- 14: Results of Wheel Tracking Test for Conventional and RMA Mixture

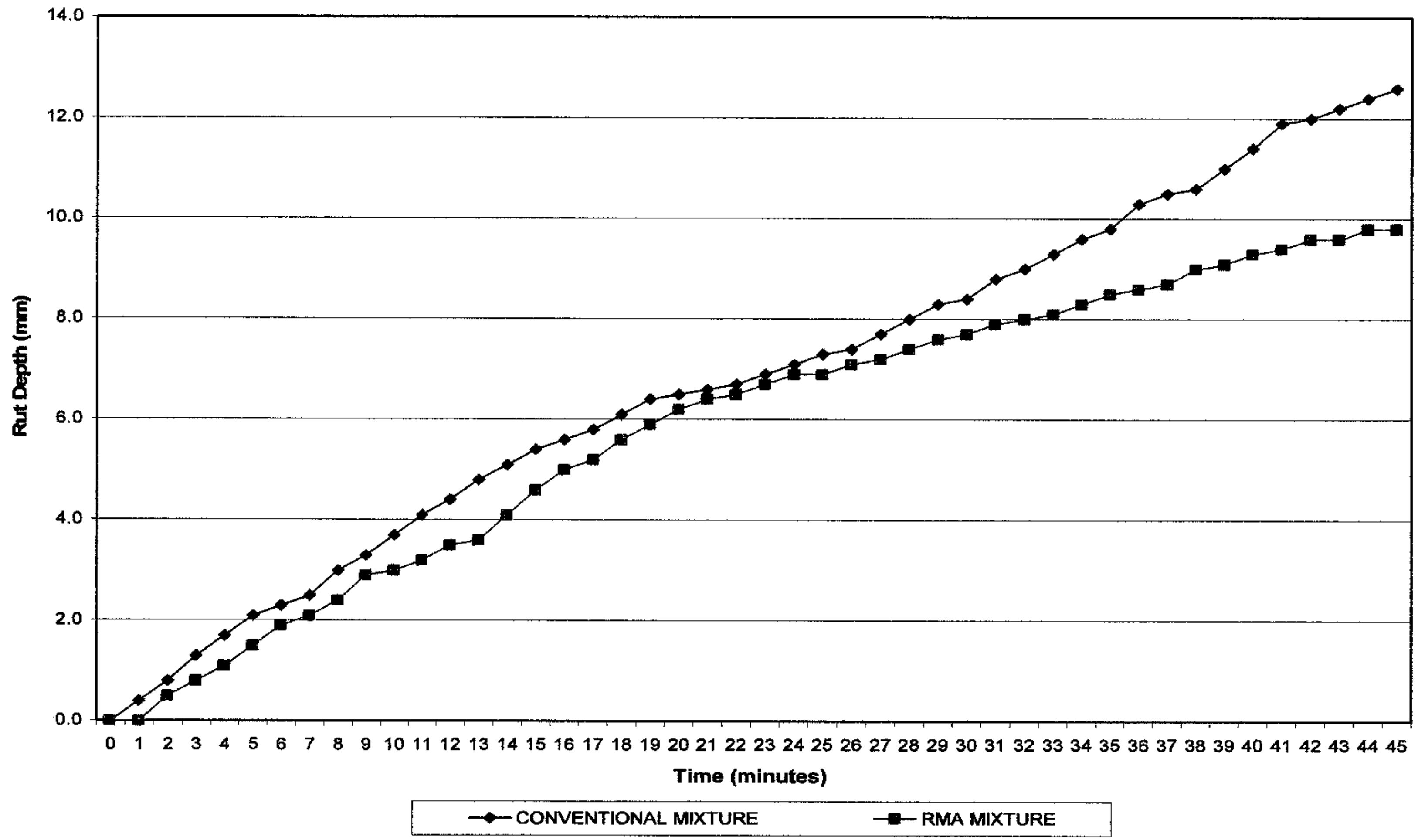


Figure 4- 25: Graph of Rut Depth versus Time for Wheel Tracking Test

4.5 Beam Fatigue Test

The Beam Fatigue Test is conducted for all specimens with 1 to 3 percent rubber particles. The binder content used is based on the optimum binder content determine earlier for both conventional and RMA mixture. Figures below shows the results obtained from the experiments for conventional mixture and RMA mixture of 1 to 3 percent of rubber particles. The red color sinusoidal graph shows the stiffness of the specimen while the green color refers to the maximum tensile strain. The loading conditions for all the specimens are **peak to peak micro-strain of 100** with **conditioning cycles of 10**.

For conventional mixture, the **initial flexural stiffness** is **1678 MPa**. The graph shows the stiffness of the specimen decrease exponentially with cycle until the specimen is failed. The result also listed the **termination stiffness** of **839 MPa**. Termination stiffness is the value of stiffness the specimen can withstand before failing. The specimen failed at **13490 cycles** which resulting in **maximum tensile stress** of **106 kPa**.

For the 1 percent RMA mixture, the graph shows a decrease in stiffness at the earlier stage of loading before it start to increase constantly. The initial flexural stiffness of 1 percent RMA mixture is **2325 MPa** while the termination stiffness of the sample to fail is **1163 MPa**. The maximum tensile stress the specimen can withstand is **214 kPa** with cyclic loading of **36510 cycles** before failing. The specimen is fail when the stiffness of the specimen has reached half of its initial stiffness. The 2 percent and 3 percent RMA mixture also shows the decreasing of stiffness before increase again constantly. The initial flexural stiffness for both mixtures is **1973 MPa** and **1771 MPa**, with cyclic loading of **112000 and 5530 cycles**. Termination stiffness listed for the mixtures is **987 MPa and 885 MPa**. Both the RMA mixtures can stand the maximum tensile stress of **160 kPa** and **151 kPa**.

All results of Beam Fatigue Test for RMA mixtures shows greater value for initial flexural stiffness, termination stiffness, and maximum tensile stress as compared to the conventional mixture result. It shows that the RMA mixture is stiffer than the conventional mixture. Most of the graphs show that the stiffness is constant at the middle stage of the experiment before failing, whereas the conventional mixture is continuously decreased. The constant increment of the stiffness in the middle stage of the experiment is due to the elastic behavior of the RMA mixture, where the rubber inside the mixture improve the elasticity of the mixture, compare to conventional mixture. The elasticity of the RMA mixture can increase the fatigue life of the pavement.

From the results, the 1 percent RMA mixture gave **38%** of stiffness improvement, but 3 percent RMA mixture is about **6%**. Even the 3 percent RMA mixture has a lower value of initial flexural stiffness and maximum tensile stress; there are still some improvements as compared with conventional mixture. An increased in mixture stiffness will in turn reduce the fatigue life at a particular strain level. It is suggested that the service life is highly dependant on the mix stiffness, the stiffer the mix the longer the life [11]. Bituminous mixture with high stiffness is desirable as at high ambient road temperature, as it can reduce rutting of the pavement. RMA mixture fulfills this requirement as it has been approved in the laboratory experiments.

The maximum number cyclic loading of the RMA specimens is expected to be larger than the conventional mixture. However, there is still an exceptional case where the maximum cyclic loading of 3 percent RMA specimen is only 5530 cycles as compared to 13490 cycles for conventional mixture. It could be due to the improper compaction of the specimens during specimen preparation or the high binder content adopted for RMA mixture. High temperature can cause pavement bleeding due to high binder content.

Thus, the results proved that the fatigue life and the stiffness of pavement are increase by using RMA mixture.

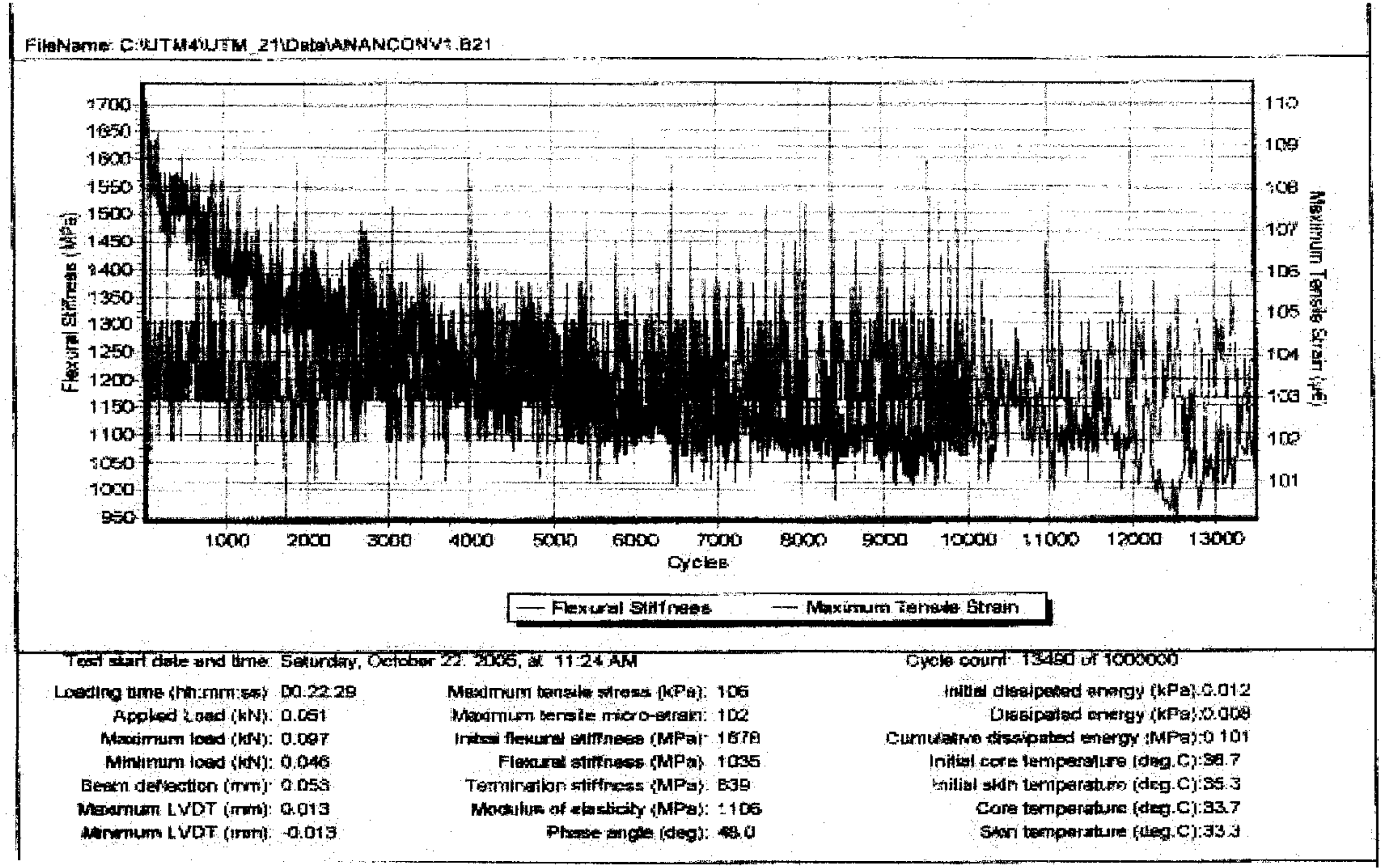


Figure 4- 26: Results of Beam Fatigue Test for Conventional Mixture

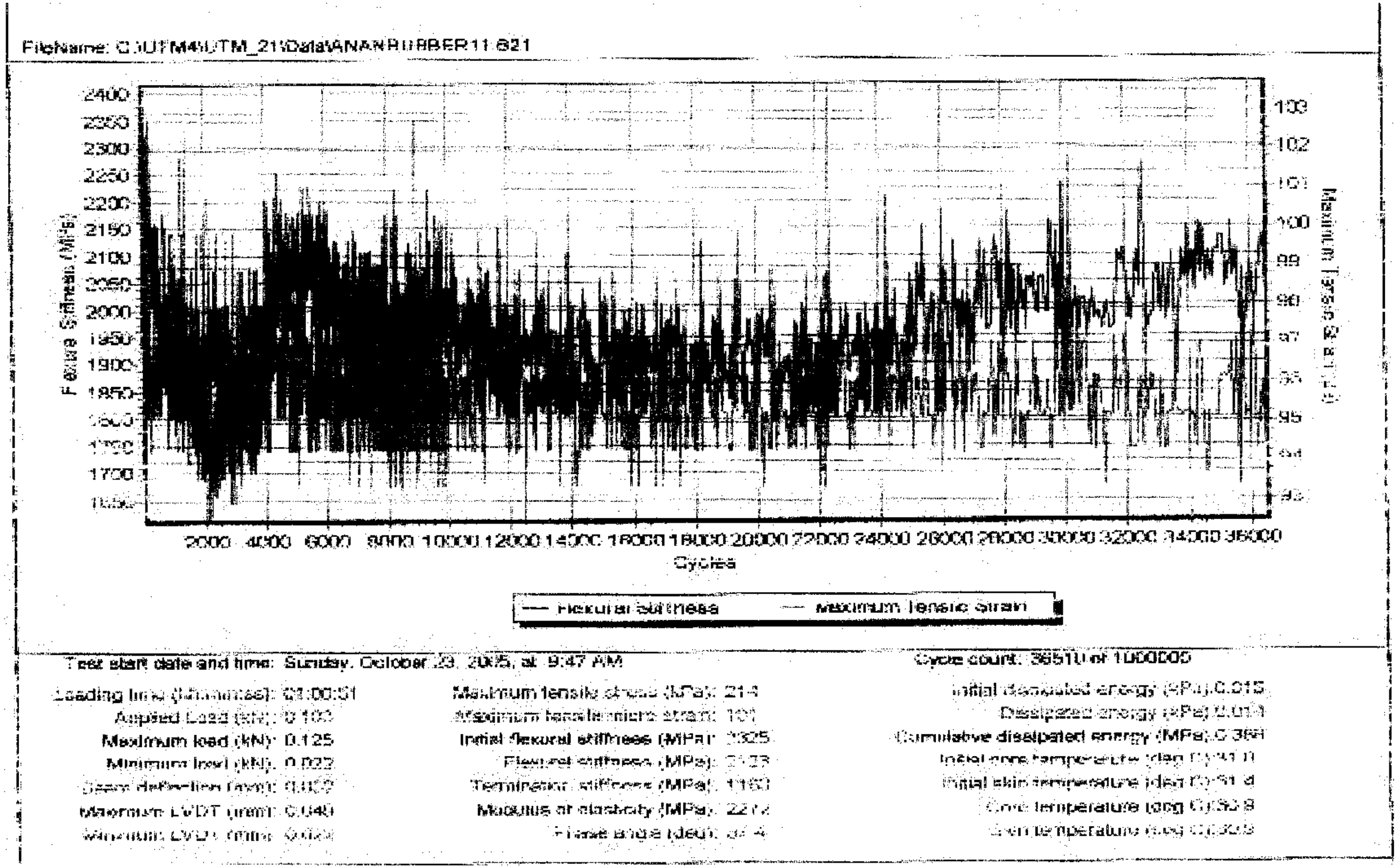
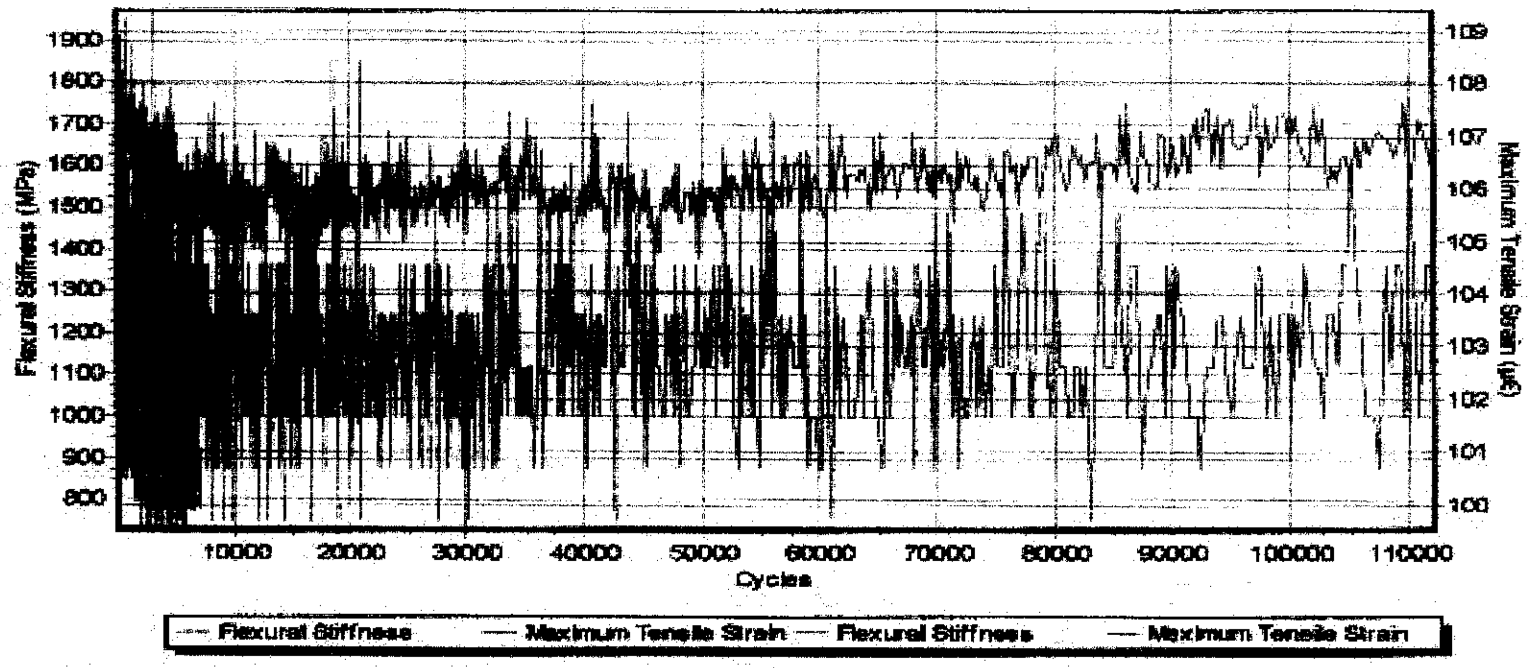


Figure 4- 27: Results of Beam Fatigue Test for 1% RMA Mixture

FileName: C:\UTM4\UTM_21\Data\ANANRUBBER222.B21



Test start date and time: Wednesday, October 26, 2005, at 8:36 AM

Cycle count: 112000 of 1000000

Loading time (hh:mm:ss): 03:06:40
Applied Load (kN): 0.079
Maximum load (kN): 0.103
Minimum load (kN): 0.024
Beam deflection (mm): 0.052
Maximum LVDT (mm): 0.022
Minimum LVDT (mm): -0.004

Maximum tensile stress (kPa): 160
Maximum tensile micro-strain: 102
Initial flexural stiffness (MPa): 1973
Flexural stiffness (MPa): 1579
Termination stiffness (MPa): 987
Modulus of elasticity (MPa): 1691
Phase angle (deg): 41.4

Initial dissipated energy (kPa):0.011
Dissipated energy (kPa):0.010
Cumulative dissipated energy (MPa):0.969
Initial core temperature (deg.C):32.0
Initial skin temperature (deg.C):31.3
Core temperature (deg.C):30.5
Skin temperature (deg C):30.4

Figure 4- 28: Results of Beam Fatigue Test for 2% RMA Mixture

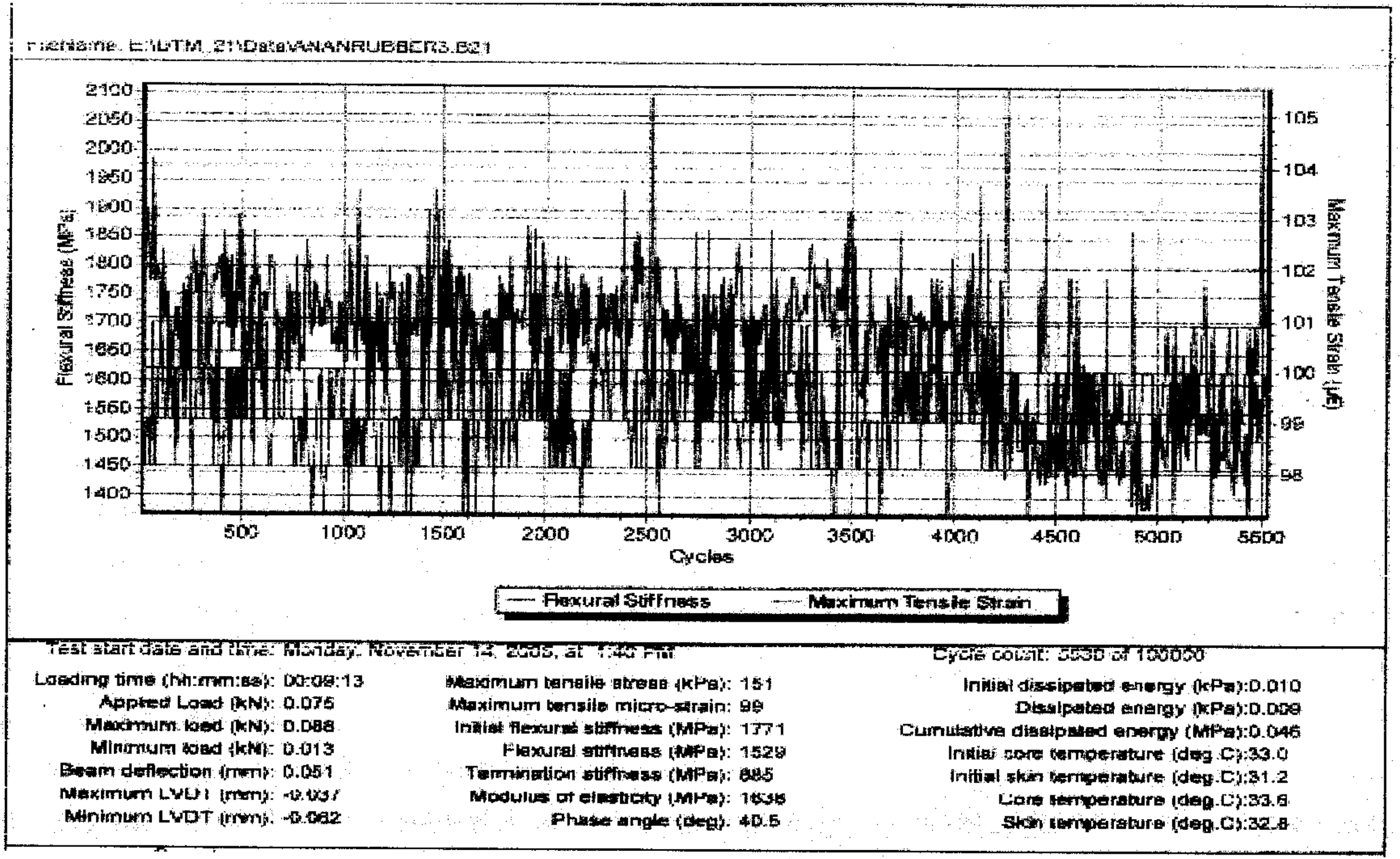


Figure 4- 29: Results of Beam Fatigue Test for 3% RMA Mixture

CHAPTER 5

5.1 Conclusion

Generally, construction of pavement using scrap tire is not common in Malaysia. Therefore, it is hopefully that through this research, the application of scrap tire in pavement could be promoted as a better performance pavement than the conventional asphalt pavement.

The research has completed all the required laboratory experiments, which are Marshall Stability Test, Wheel Tracking Test, and Beam Fatigue Test as to determine the performance of the Rubber Modified Asphalt (RMA) mixture.

Thus, the research has achieved its objectives of producing RMA mixtures by replacing certain proportion of fine aggregate with rubber particles and identifying possible properties improvements by RMA mixture. The specimens are successfully produced using the Marshall Mix Design method and there are improvements of stiffness and fatigue life, as well as resistant to permanent deformation by introducing rubber particles in the asphalt mixture. RMA mixture has high viscosity which is desirable for stability and resistance to fatigue failure.

The results of the laboratory experiments conducted earlier proved that RMA mixture can extend the life of the asphalt pavement compare to the conventional mixture. The elasticity properties of the RMA mixture can increase the time of asphalt pavement to experience fatigue cracking and rutting in the early years of design life. Thus, the resistant to cracking and permanent deformation is increase. Rubber additives is proved to enhance the elastic responses of bitumen at high ambient temperature and result in a material that has a marked increase in resistance to permanent deformation simultaneously with reduce brittleness at low temperature.

Perhaps the research can help introducing and promoting the used of scrap tires in asphalt mixture for better performance pavement. Even tough the initial cost would be higher compare to construction of conventional asphalt pavement, but the reducing of maintenance cost is preferable as the RMA pavement extending the pavement's life and improves the resistance to cracking and deformation. Furthermore, the RMA pavement can give smoother riding environment to the drivers as RMA pavement is quieter, which has been proved by previous researchers.

5.2 Recommendation

This research presents the laboratory findings of utilizing the scrap tires in asphalt pavement in terms of deformation and fatigue resistance. Thus, following recommendations are suggested for better assessment of the influences.

1) Perhaps the usage of the scrap tires in asphalt pavement can be widely used as Malaysia experiencing a lot of pavement problems, such as cracking and deformation. Mostly in the early years of the design life due to the high traffic loading which increase every year. In another way, it can reduce the disposal problem of the scrap tires in Malaysia.

2) A factory can be constructed to grind the rubber into pieces to be use in asphalt pavement. Variety size of rubber particles is accepted if it is still within the range of 2.0 mm to 4.2 mm. It is to ensure that the rubber particles size is similar to the size of fine aggregate. It is suggested to use the motorcycle's tires and motorcar's tires as the tires are thicker than bicycle's tires.

3) A trial field is recommended to confirm the laboratory findings and perhaps can determine the level of noise reduction by using the scrap tires in asphalt pavement that could not be done in this research.

Although the rubberized pavement require high initial cost, but it will result in less maintenance cost through out the design life. Also it will give a better performance pavement and riding environment.

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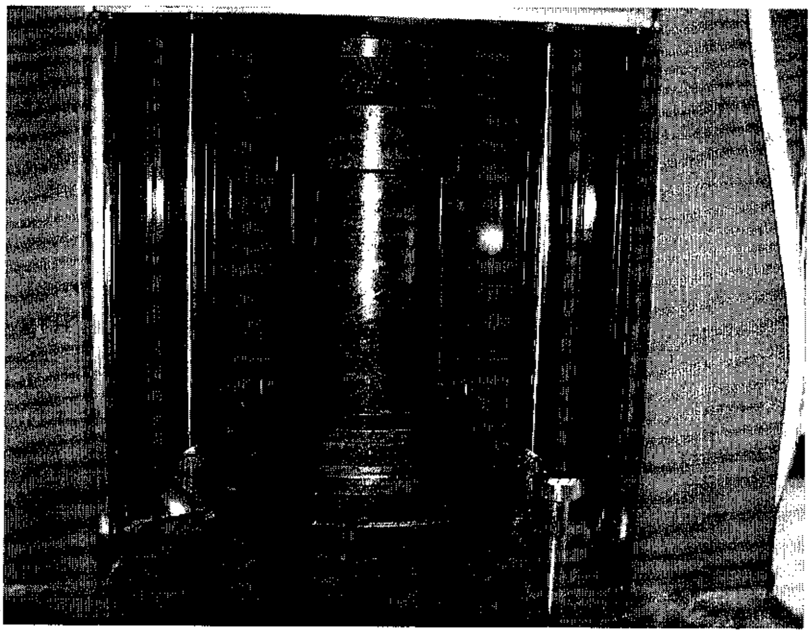
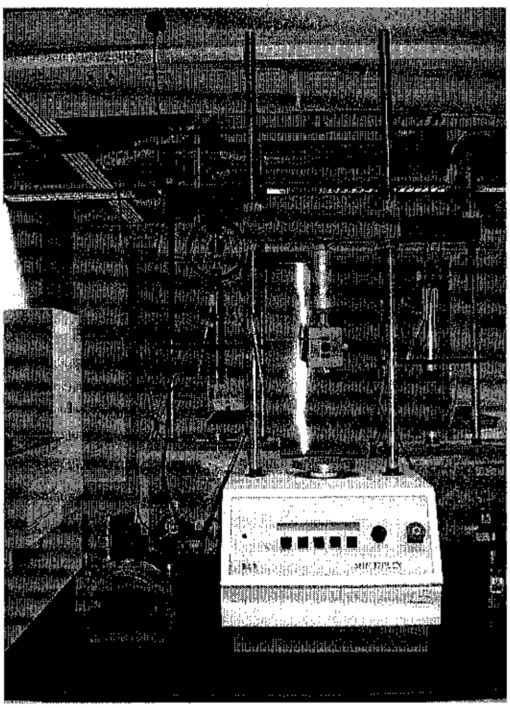
APPENDICES

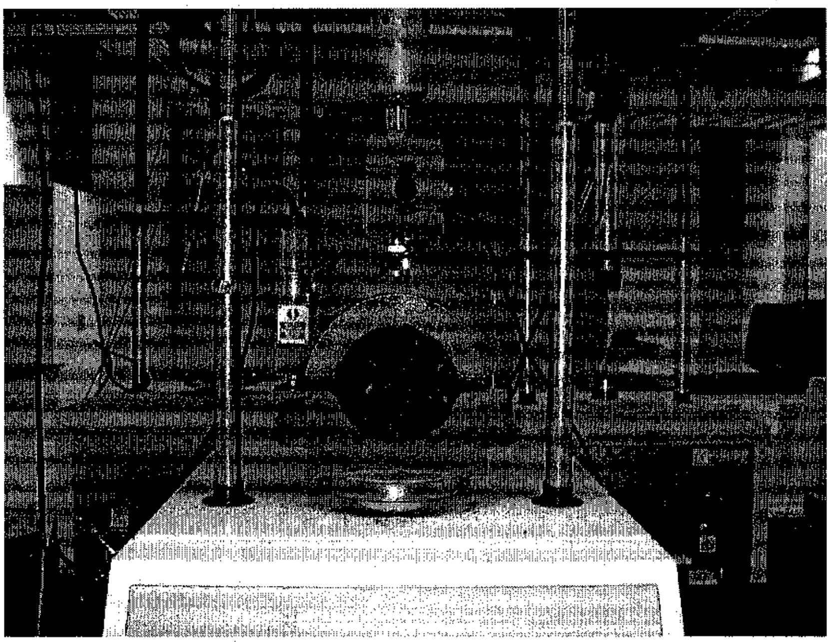
Volume of Specimen (cm^3)	Approximate Thickness of Specimen (cm)	Correction Coefficient
200 – 213	2.54	5.56
214 – 225	2.70	5.00
226 – 237	2.86	4.55
238 – 250	3.02	4.17
251 – 264	3.18	3.85
265 – 276	3.34	3.57
277 – 289	3.49	3.33
290 – 301	3.65	3.03
302 – 316	3.81	2.78
317 – 328	3.97	2.50
329 – 340	4.13	2.27
341 – 353	4.29	2.08
354 – 367	4.45	1.92
368 – 379	4.60	1.79
380 – 392	4.76	1.67
393 – 405	4.92	1.56
406 – 420	5.08	1.47
421 – 431	5.24	1.39
432 – 443	5.40	1.32
444 – 456	5.56	1.25
457 – 470	5.72	1.19
471 – 482	5.88	1.14
483 – 495	6.03	1.09
496 – 508	6.19	1.04
509 – 522	6.35	1.00
523 – 535	6.51	0.96
536 – 546	6.67	0.93
547 – 559	6.83	0.89
560 – 573	6.99	0.86
574 – 585	7.14	0.83
586 – 598	7.30	0.81
599 – 610	7.46	0.78
611 – 625	7.62	0.76

Appendix 1: Coefficient Factor (C.F) for Adjusting Stability Values

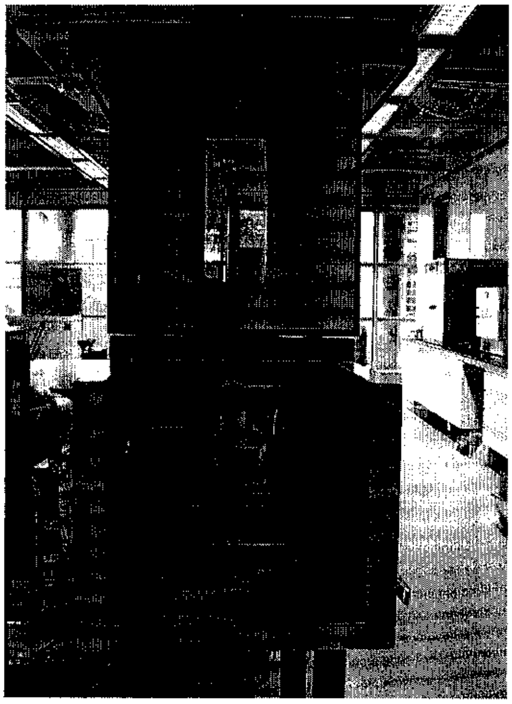


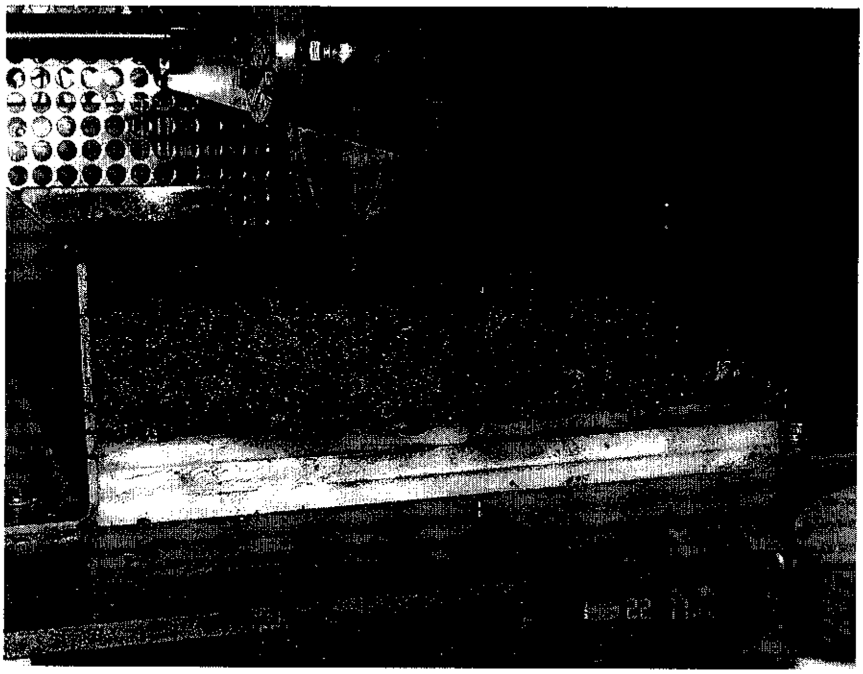
Appendix 2: Above: The Gyratory Machine, Below: Specimen Compacted inside the Machine, for Marshall Mix Design.



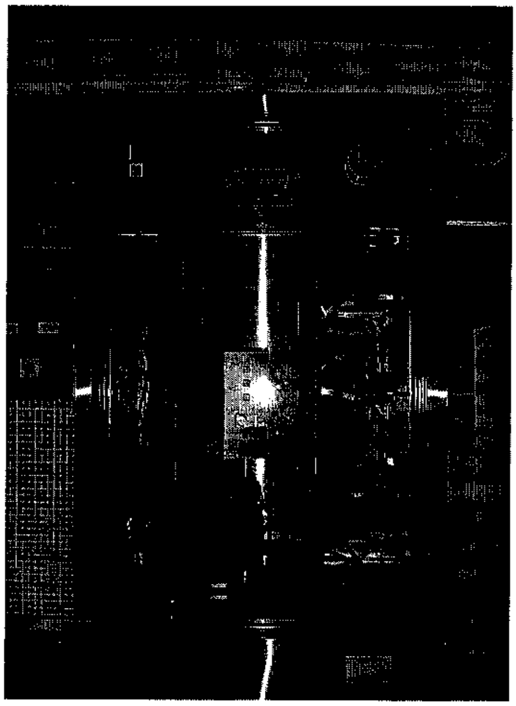


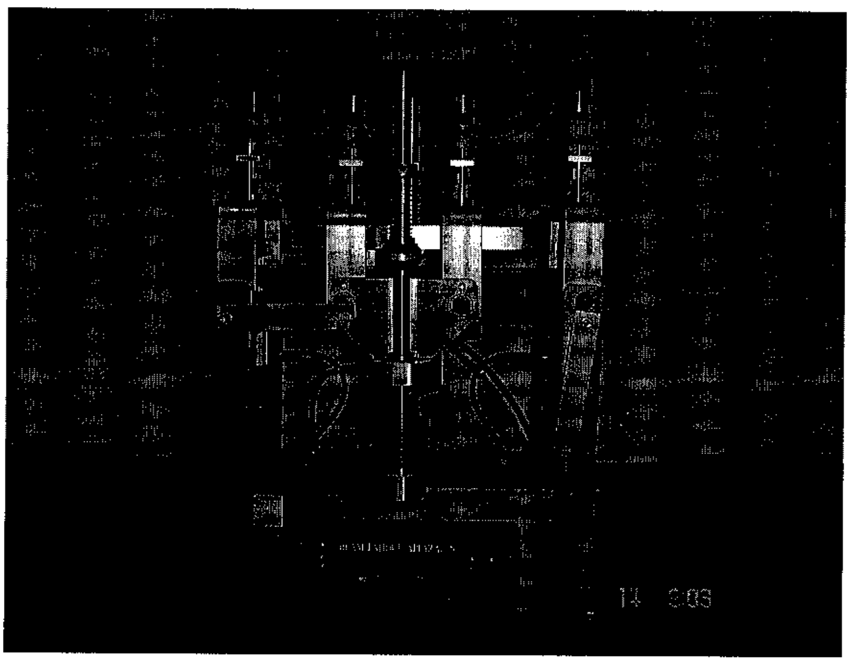
Appendix 3: Above: Marshall Testing Rig Equipments, Below: Specimen Tested Using the Equipments, for Marshall Stability Test.





Appendix 4: Above: The Wessex Wheel Tracking Machine, Below: The Specimens Tested in the Machine, for Wheel Tracking Test.





Appendix 5: Above: Universal Asphalt Tester (MATTA) Machine, Below: The Beam ˀatigue Apparatus with Specimen to be Place inside the Machine, for Beam Fatigue Test.

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Searching Topics																			
2	Appointing Supervisor																			
3	Submission of FYP Topic																			
4	Define the Project																			
5	Research on the Project																			
6	Preparation and Submission of Preliminary Report																			
7	Preparing Literature Review																			
8	Preparation of Specimens																			
9	Laboratory Experiments																			
10	Preparation and Submission of Progress Report																			
11	Preparation and Submission of Interim Report																			
12	Preparation of FYP Presentation																			
13	FYP Presentation																			

Appendix 6: Schedule for First Semester of Two Semester of Final Year Project

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Preparing Rubber Specimens																				
2	Laboratory Experiments																				
3	Preparing of Progress Report 1																				
4	Submission of Progress Report 1																				
5	Laboratory Results Analysis																				
6	Preparing of Progress Report 2																				
7	Submission of Progress Report 2																				
8	Preparing First Draft Dissertation Final Report																				
9	Submission of First Draft Dissertation Final Report																				
10	Preparation of FYP Presentation																				
11	FYP Presentation																				
12	Submission of Project Dissertation																				

Appendix 7: Schedule for Second Semester of Two Semester of Final Year Project